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PARATRANSIT VEHICLE TEST AND EVALUATION
Volume I: Ride Comfort and Quality Tests

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FINAL REPORT

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16. Abstract

The vehicles presently available for paratransit service do not cover the full spectrum of required characteristics necessary for public transportation. Therefore, specifications were developed by the U.S. Government for a vehicle specifically for use in paratransit service. Prototype vehicles were manufactured for the Government by two different manufacturers (ASL Engineering and Dutcher Industries). Dynamic Science, Inc., conducted an independent series of tests and evaluations of the two prototype vehicles. The program was structured to provide performance data on the prototypes compared to a baseline vehicle that will be used to upgrade future redesigns. The program consisted of five separate test series: 1) Ride Comfort and Quality; 2) Acceleration and Interior Measurement; 3) Handling; 4) Fuel Economy; and 5) Noise. The results of the program are documented in a five-volume technical report, and each volume corresponds to one of the individual test series.

This volume (Volume I) presents the test procedures and results of the ride comfort and quality test series. The objectives of this test series were to measure the ride characteristics of the test vehicles and to determine if and how well they satisfied standards for ride quality. The tests measured the ride characteristics of the two prototype vehicles and a baseline passenger car as they were driven at controlled speeds over a specially constructed ride course. The vibratory motions impacted to the driver and passengers were evaluated against the criteria in International Standard ISO 2631 for driver fatigue and passenger comfort.

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PREFACE

This final report, Volume I, summarizes the ride comfort and quality testing on the Paratransit Evaluation and Testing Contract. The program was structured to provide performance data on the prototypes compared to a baseline vehicle that will be used to upgrade future redesigns.

The program was conducted by Dynamic Science, Inc. under Contract DOT-TSC-1241 with the Transportation Systems Center (TSC) of Cambridge, Massachusetts for the Urban Mass Transportation Administration. The contract was technically managed by Mr. Jim Kakatsakis and Mr. Joe Picardi of TSC.

The opinions and findings expressed in this publication are those of the authors and not necessarily those of the Government.

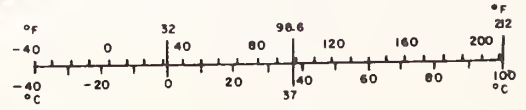
METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
	LENGTH			
in	inches	2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
	AREA			
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	he
	MASS (weight)			
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
	VOLUME			
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
	TEMPERATURE (exact)			
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
	LENGTH			
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
	AREA			
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
	MASS (weight)			
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
	VOLUME			
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
	TEMPERATURE (exact)			
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



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1.0 INTRODUCTION

The paratransit mode of transportation provides an alternative between transit in privately owned and operated vehicles and scheduled mass transit systems. Paratransit includes such systems as dial-a-ride, taxi, and jitney service. It is of vital importance to people without individual cars or ready access to regular mass transit and to people of limited mobility. The vehicles presently available for paratransit service, however, do not cover the full spectrum of required characteristics. They are slightly modified versions of vehicles designed for different purposes. As such, they are not as efficient in their operation nor as easy to enter and exit as is desirable in this type of transportation.

Therefore, the Urban Mass Transportation Administration (UMTA), working through the Transportation Systems Center (TSC), developed specifications for a vehicle specifically for use in paratransit which combines a number of desirable features without compromising important performance parameters. Prototype vehicles were manufactured for UMTA by two different manufacturers (ASL Engineering and Dutcher Industries) according to these specifications. The primary features of the vehicles are a low pollution, quiet, efficient propulsion system combined with a body designed for the comfort and convenience of both the passengers and driver. The vehicles include provisions for easy ingress and egress for the general public as well as the elderly and handicapped, including the easy ingress/egress and accomodation of a wheelchair passenger.

Dynamic Science, Inc. was selected by UMTA to conduct an independent series of tests and evaluations of the two prototype paratransit vehicles (PTV). These tests were designed to provide additional information on the ride quality and comfort, fuel economy, performance, and handling characteristics of the two vehicles.

A compact passenger car (Chevrolet Nova) was utilized as a baseline test vehicle throughout the test series to furnish comparative data for the evaluations.

The paratransit vehicle testing and evaluation program consisted of six major tasks. The first task consisted of initial vehicle inspection, test preparation, and driver familiarization efforts conducted upon delivery of the vehicles to the Dynamic Science test facility. The remaining five tasks consisted of conducting and evaluating the results of five separate test series. These series were:

- Ride Comfort and Quality Test Series which measured the ride characteristics of the test vehicles to determine if and how well they satisfy accepted standards of ride quality.
- Acceleration and Interior Measurement Test Series which determined the acceleration characteristics and available interior space of the vehicles in order to evaluate their suitability for urban paratransit use.
- Handling Test Series which determined the steering and handling characteristics of the PTVs and allowed their characteristics to be compared with those of the baseline test vehicle.
- Fuel Economy Test Series which obtained fuel economy data for the PTVs under actual road conditions with various driving cycles.
- Noise Test Series which measured the acoustic noise generated by the vehicles and the noise environment inside the passenger and driver compartments.

The Paratransit Test and Evaluation Program is documented in five separate volumes as follows:

Volume 1 - Ride Comfort and Quality Tests

Volume 2 - Acceleration and Interior Measurement Tests

Volume 3 - Handling Tests

Volume 4 - Fuel Economy Tests

Volume 5 - Noise Tests.

This volume (Volume 1) presents the test procedures and results of the ride comfort and quality tests conducted on the two PTV prototypes and the baseline test vehicle.

2.0 TEST DESCRIPTION

2.1 TEST OBJECTIVES

The objectives of this test series were to measure the ride characteristics of the test vehicles and to determine if and how well they satisfied accepted standards for ride quality. The vibratory motions impacted to the driver and passengers were to be evaluated in terms of fatigue, decreased proficiency of the driver, and reduced comfort of the passengers.

2.2 TEST DESIGN

The ride comfort and quality tests consisted of measuring vibratory motion of the two paratransit prototypes and the baseline vehicle as they were driven over two test courses. The tests were designed to be representative of urban operating conditions under a variety of road surfaces, vehicle speeds, and load conditions.

The test courses consisted of the Dynamic Science ride quality course, which includes various types of surface irregularities, and an urban driving course, incorporating typical driving accelerations and decelerations, on a smooth test track.

The ride test conditions are listed in Table 1. The tests over the ride quality course were conducted at five steady-state speeds while the urban test speed was varied throughout the two-mile course. Three different loading conditions were used in the baseline vehicle. Passenger loading was accomplished with Alderson VIP-50 anthropomorphic dummies. One of the dummies was instrumented with chest accelerometers and used in all test runs (except the heavy loaded condition).

TABLE 1. RIDE TEST CONDITIONS

Course	Test Speed (mph)	Passenger Loading	
		Paratransit Vehicles	Baseline Vehicle
Ride	5, 10, 20, 30, and 40	1 Wheelchair	1 Rear Seat
Ride	5, 10, 20, 30, and 40	1 Rear Seat	--
Ride	5, 10, 20, 30, and 40	1 Wheelchair, 2 Rear Seat	3 Rear Seat
Urban	Variable Average = 15.6	1 Wheelchair	1 Rear Seat
Total Number of Tests		16	11

3.0 TEST VEHICLES

The test vehicles consisted of two prototype paratransit vehicles (one manufactured by ASL Engineering and the other by Dutcher Industries) and one baseline vehicle (Chevrolet Nova). These vehicles are shown in Figure 1.

3.1 ASL PARATRANSIT VEHICLE

The ASL PTV (Figure 2) is a front engine, front drive vehicle which can accommodate a maximum of five seated passengers or three seated passengers plus a wheelchair. Ingress/egress is accomplished through remotely operated sliding doors on each side of the vehicle. An electrically powered loading ramp may be extended on the right side of the vehicle to permit unassisted ingress and egress for wheelchair passengers.

The driver's compartment is separated from the passenger compartment by a bullet-resistant partition. An intercom system is provided for communication between the two compartments. All seating positions are equipped with belt restraints and a restraint system is also provided to fasten the wheelchair securely to the vehicle.

3.2 DUTCHER PARATRANSIT VEHICLE

The Dutcher PTV (Figure 3) is a rear engine, rear drive vehicle which accommodates five seated passengers or four seated passengers plus a wheelchair. Hydraulically actuated bi-fold doors on each side of the vehicle permit passenger ingress and egress. An electrically powered loading ramp extending on the right side of the vehicle allows wheelchair ingress and egress.

Figure 1. Test Vehicles Left-to-Right: Dutcher PTV, ASL PTV, Chevrolet Nova.

Figure 2. ASL Paratransit Vehicle.

Figure 3. Dutcher Paratransit Vehicle.

As in the ASL PTV, the Dutcher PTV contains a driver compartment which is completely separated from the passenger compartment by a transparent partition. Communication between passengers and driver is accomplished through an intercom system. Restraints are provided for all seating positions and for the wheelchair.

3.3 BASELINE TEST VEHICLE

The baseline test vehicle which was used for comparative evaluation of the PTV test results was a 1977 Chevrolet Nova 6. The criteria for the selection of the baseline vehicle were:

- Compact Size
- 4-Door Passenger Car
- 6-Cylinder Engine
- Automatic Transmission
- Air Conditioning System
- Radial Tires
- Weight, Width, and Length Comparable to the Paratransit Vehicle
- Mileage Less Than 5000 Miles.

The Nova was selected because it fulfills all of the above requirements and, in addition, is more prevalent and more commonly known than any of the other vehicles which met the criteria.

3.4 COMPARISON OF BASIC VEHICLE CHARACTERISTICS

The basic test vehicle characteristics are listed in Table 2. The characteristics of the two PTV vehicles are similar in most instances. The major differences between the two vehicles lie in the engine location/drive configuration and in the front-to-rear weight ratio (1.59 for the ASL and 0.60 for the Dutcher).

TABLE 2. BASIC TEST VEHICLE CHARACTERISTICS

Vehicle Parameter	ASL PTV	Dutcher PTV	Nova (Baseline)
1. Dimensions			
Height (in.)	70.8	80.1	55.1
Width (in.)	72.5	72.8	73
Length (in.)	184	172.5	197.1
Wheelbase (in.)	108.3	106.8	111.4
Track			
- Front (in.)	63.4	63.5	61
- Rear (in.)	63.2	61.9	59.3
2. Weight			
Curb Weight (lb)	3510	3021	3450
- Front Rear Ratio	1.59	0.60	1.23
3. Minimum Turning			
Diameter (ft)	37.5	33.8	40.2
4. Engine			
Location	Front	Rear	Front
No. of Cylinders	4	4	6
Displacement ($in.^3$)	114.5	120.3	250
Horsepower	95	86	110
Compression Ratio	8:1	7.6:1	8.25:1
5. Transmission			
Automatic/Manual	Automatic	Automatic	Automatic
No. of Forward Speeds	3	3	3
6. Brakes			
Power/Manual	Power	Manual	Power
Front	Disc	Disc	Disc
Rear	Drum	Drum	Drum
7. Tire Size	ER78-14	Front BR78-13 Rear ER78-14	FR78-14
8. Steering			
Power/Manual	Power	Manual	Power
Type	Rack & Pinion	Rack & Pinion	Standard
9. Drive			
Front/Rear	Front	Rear	Rear
Ratio	4.11	4.57	2.73
10. Fuel Capacity (gal)	15	15	21

4.0 TEST FACILITIES

The ride quality tests were conducted at two locations, both on the Dynamic Science Test Facility shown in Figure 4. The urban driving tests were conducted on the two-mile oval (Item 7, Figure 4), and the ride tests were conducted on the ride quality course (Item 17, Figure 4).

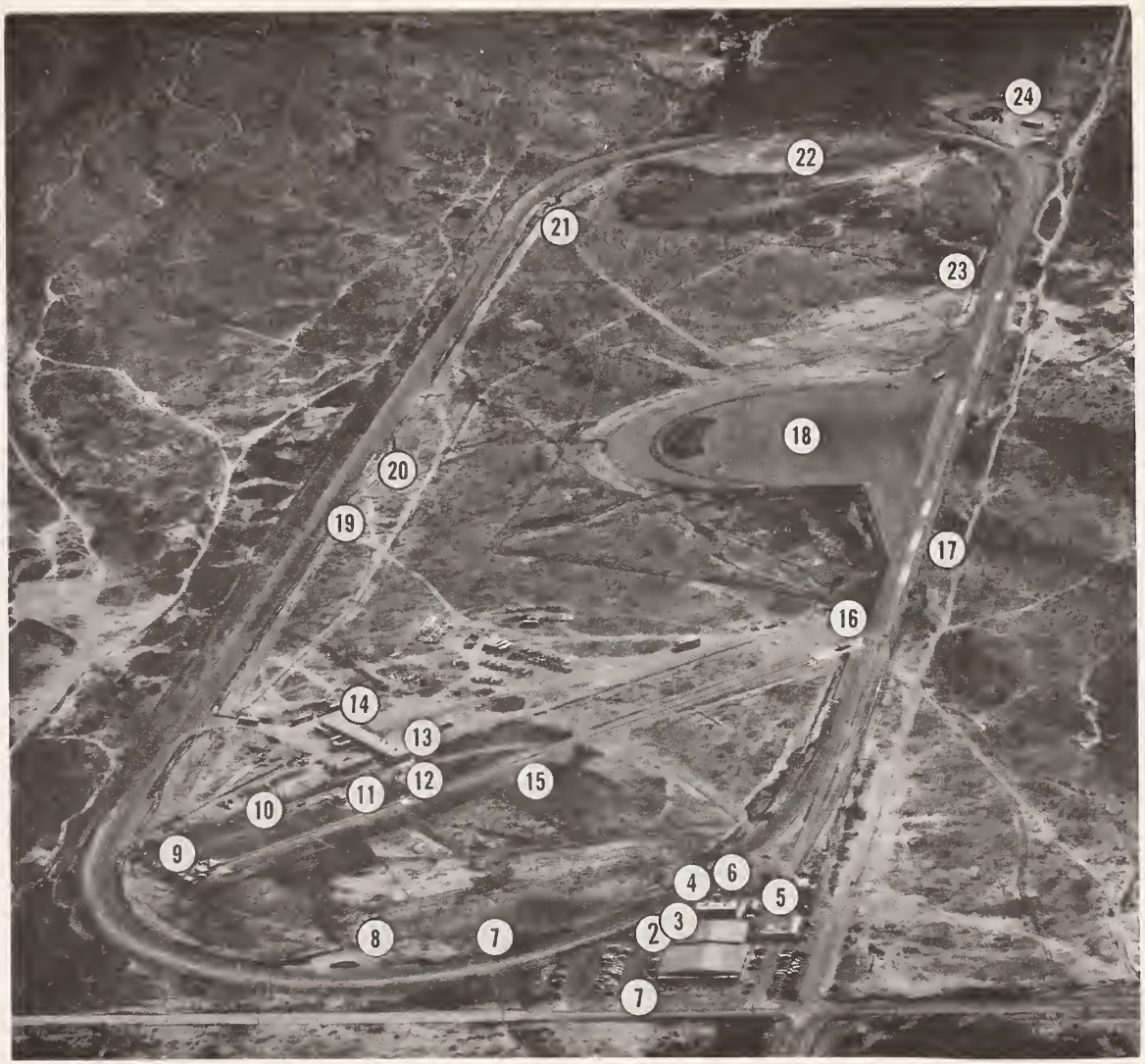
4.1 URBAN DRIVING COURSE

The two-mile oval is a minimum two lanes wide (fourteen feet each) throughout. The inside lane was utilized for the urban driving tests since it has no appreciable cross slope. Its surface is of asphaltic concrete with no perceptible bumps or dips due to overlapping paving strips. The pavement grade of the straightaways is less than 1 percent.

The urban driving course layout is illustrated in Figure 5. The course was marked using ground supported posts which extended at least four feet above the ground and had the mileage marked on them so that they could be easily read from the test vehicle while it was traversing the course. The posts appeared at the 0.0, 0.2, 0.3, 0.5, 0.7, 0.8, 1.0, 1.2, 1.3, 1.5, 1.7, 1.8, and 2.0 mileage positions. Each post position was within five feet of the desired position.

4.2 RIDE QUALITY COURSE

The ride quality course was designed to represent a spectrum of conditions, including some of the worst case conditions that might exist on city streets and highways, and is based on measurements of real roads. The layout of the course is shown in Figure 6. The course is 12 feet wide, 2,200 feet long, with 1,700 feet



1. ENGINEERING/ADMINISTRATION CENTER
2. MECHANICAL/INSTRUMENTATION SHOPS
3. DUMMY CALIBRATION LABORATORY
4. GARAGE/MAINTENANCE SHOP
5. ENVIRONMENTAL CHAMBER
6. STATIC CRUSH FACILITY
7. TWO-MILE OVAL
8. TURNAROUND (TYPICAL OF TWO)
9. BARRIER IMPACT FACILITY
10. DROP TOWER/SLED TEST FACILITY
11. CENTRAL DATA ACQUISITION AND CONTROL STATION
12. PENDULUM FACILITY
13. NONMETALLICS LABORATORY
14. TEST SERVICE FACILITY
15. VEHICLE-TO-VEHICLE TEST FACILITY
16. ROLLOVER TEST FACILITY
17. RIDE QUALITY COURSE
18. SKID PAD
19. HIGH AND LOW SKID NUMBER BRAKING LANES
20. SALT WATER TROUGH
21. BELGIAN BLOCK
22. PARKING BRAKE TEST RAMP
23. PULL-OFF AREA (TYPICAL OF THIRTEEN)
24. BALLISTIC TEST RANGE

Figure 4. Aerial View of Dynamic Science Deer Valley Facility.

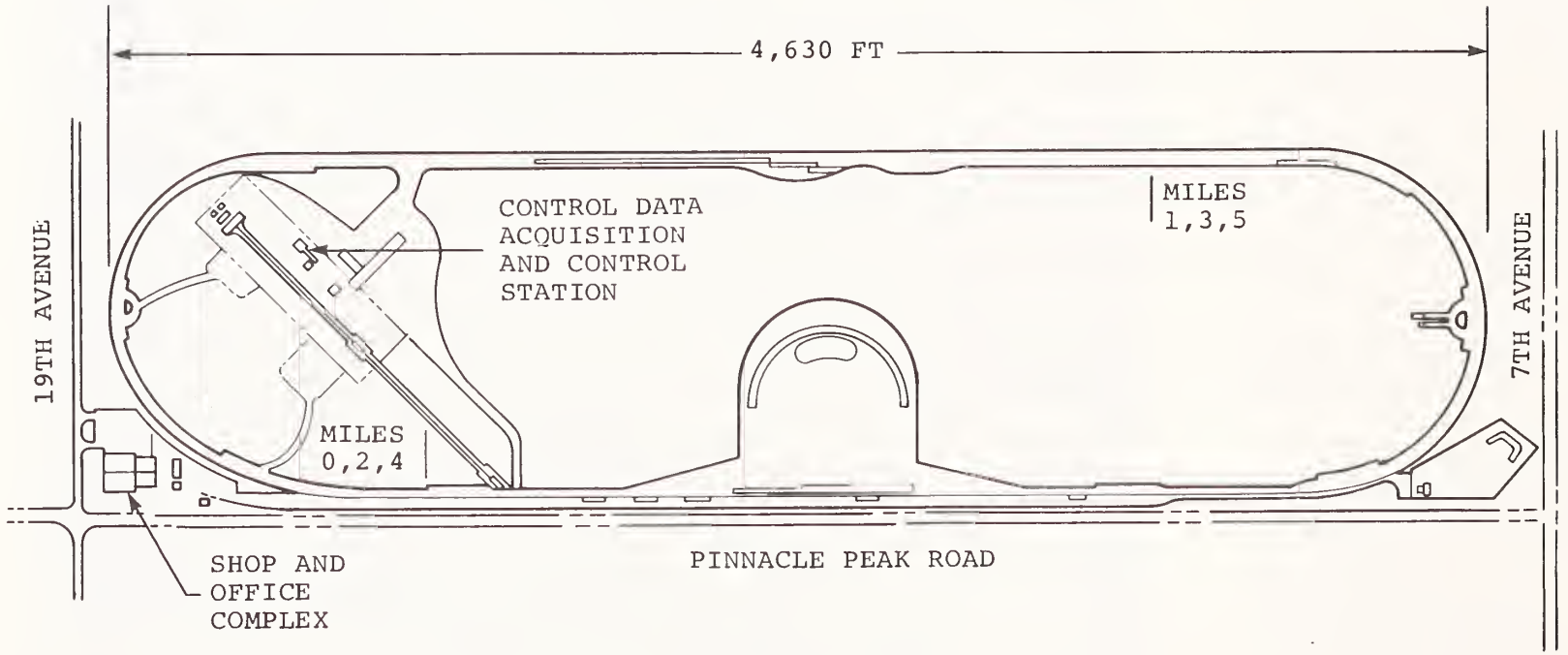


Figure 5. Course Layout for Fuel Economy.

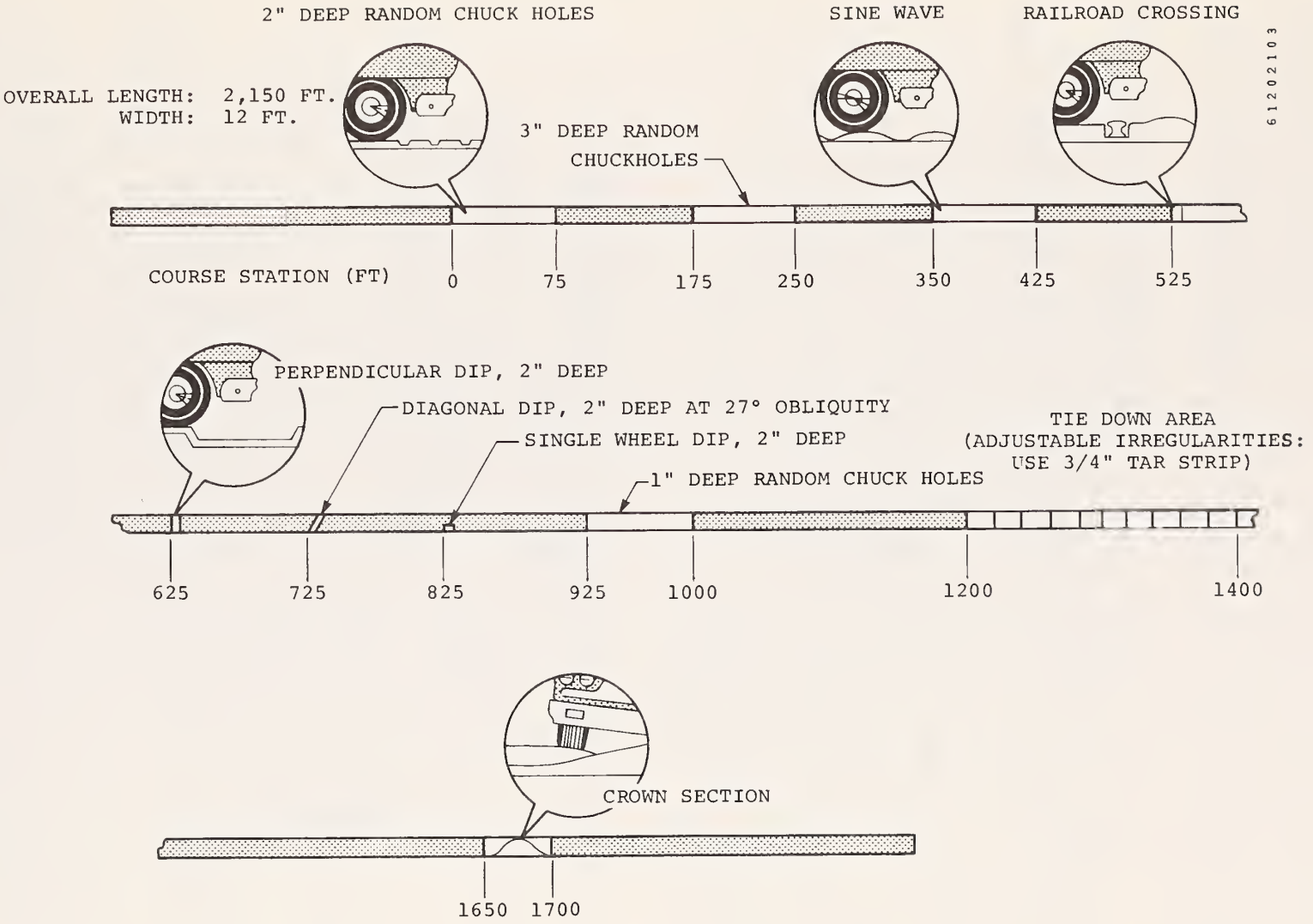


Figure 6. Ride Quality Course Layout.

devoted to contoured obstacles. There are 250 feet at each end for run-in and run-out. The course is adjacent to the south straightaway of the two-mile oval track and thus can be easily and safely entered at speeds up to 60 mph.

The various disturbances are spaced such that the vehicle can select any combination of disturbances desired simply by changing lanes from the adjacent track onto the disturbance lane for the duration of that disturbance and then back again. The segments of the course used for the ride comfort and quality tests are listed in Table 3. The low-speed tests were performed by traversing the first 1000 feet of the course, ending just beyond the 1-inch deep chuckholes. The high-speed tests were performed on the latter portion of the course, starting with the 1-inch deep chuckholes and continuing over the 3/4-inch-high tar strip simulators and crown section. The entire course is described in detail in Appendix A.

TABLE 3. LOW-SPEED AND HIGH-SPEED RIDE QUALITY COURSE

Course	Test Speed	Course Layout (Course Station, ft)	Course Length (ft)
Low Speed	<15 mph	0 to 1000	1000
High Speed	>15 mph	925 to 1700	775

5.0 TEST PROCEDURES

5.1 TEST INSTRUMENTATION

5.1.1 Required Measurements

The primary variables measured during the ride comfort and quality testing were:

1. Vehicle velocity.
2. Vehicle vertical acceleration versus time at two locations on the vehicle floor:
   - Driver's compartment or area (all vehicles)
   - Wheelchair passenger area (paratransit vehicles only)
   - Rear seat passenger area (baseline vehicle only).
3. Vehicle roll acceleration versus frequency at the vehicle center of gravity.
4. Triaxial dummy chest acceleration versus time, for all but the heavy loaded condition in Table 4.
5. Vibration input to driver and passenger(s), according to Table 4.

5.1.2 Instrumentation Specifications

The specifications for the test instrumentation are listed in Table 5.

A Labeco fifth wheel was used to measure vehicle velocity. The output of the fifth wheel was inputted into a Labeco DD1.1 speedometer for visual display of velocity.

One Alderson VIP-50 anthropomorphic dummy was instrumented with three orthogonal accelerometers mounted in its chest cavity to measure dummy referenced vertical, lateral, and longitudinal accelerations.

TABLE 4. REQUIRED VIBRATION INPUT AND DUMMY ACCELERATION MEASUREMENTS

	Paratransit Vehicles			Baseline Vehicle		
Course	Passenger Loading	Vibration Input Measurements	Dummy Acceleration Measurements	Passenger Loading	Vibration Input Measurements	Dummy Acceleration Measurements
Ride	1 Wheelchair	Driver, Passenger	Passenger	1 Rear Seat	Driver, Passenger	Passenger
Ride	1 Rear Seat	Driver, Passenger	Passenger	--	--	--
Ride	1 Wheelchair, 2 Rear Seat	Driver, Wheelchair Passenger, 1 Rear Seat Passenger	None	3 Rear Seat	Driver, 2 Passengers	None
Urban	1 Wheelchair	Driver, Passenger	Passenger	1 Rear Seat	Driver, Passenger	Passenger

TABLE 5. RIDE QUALITY INSTRUMENTATION LIST

Measurand	Type of Transducer	Manufacturer and Model	Full-Scale Range	Full-Scale Transducer Accuracy
Vehicle Velocity	Fifth Wheel	Labeco TT481 With DD-1.1 Readout	100 mph	0.5%
Vehicle Roll	Angular Accelerometer	Schaevitz Engineering ASBP-50	50 radians/sec^2	0.1%
Dummy Vibration	Strain Gauge Accelerometer	Bell and Howell 4-202-0001	±5G	0.75%
Vehicle Vibration	Strain Gauge Accelerometer	Statham A6-10-350	±10G	0.75%
Input Vibration to Driver/ Passengers	Strain Gauge Accelerometer	Statham F-10-20	±10G	0.6%
Event	Switch	Dynamic Science	on-off	--
Vehicle Acceleration	Manometer	Ammco 7375	-32.2 to 15 ft/sec^2	±0.5 ft/sec^2
Elapsed Time	Stopwatch	Breitling	--	±.05 sec

Three seat discs were instrumented with three accelerometers each, mounted to measure the vertical, lateral and longitudinal vibration input to a seated subject. The discs shown in Figure 7 were placed on the seats beneath the subjects during the testing. They were designed so that they did not significantly influence the vibration transfer between the vehicle seat and the subject.

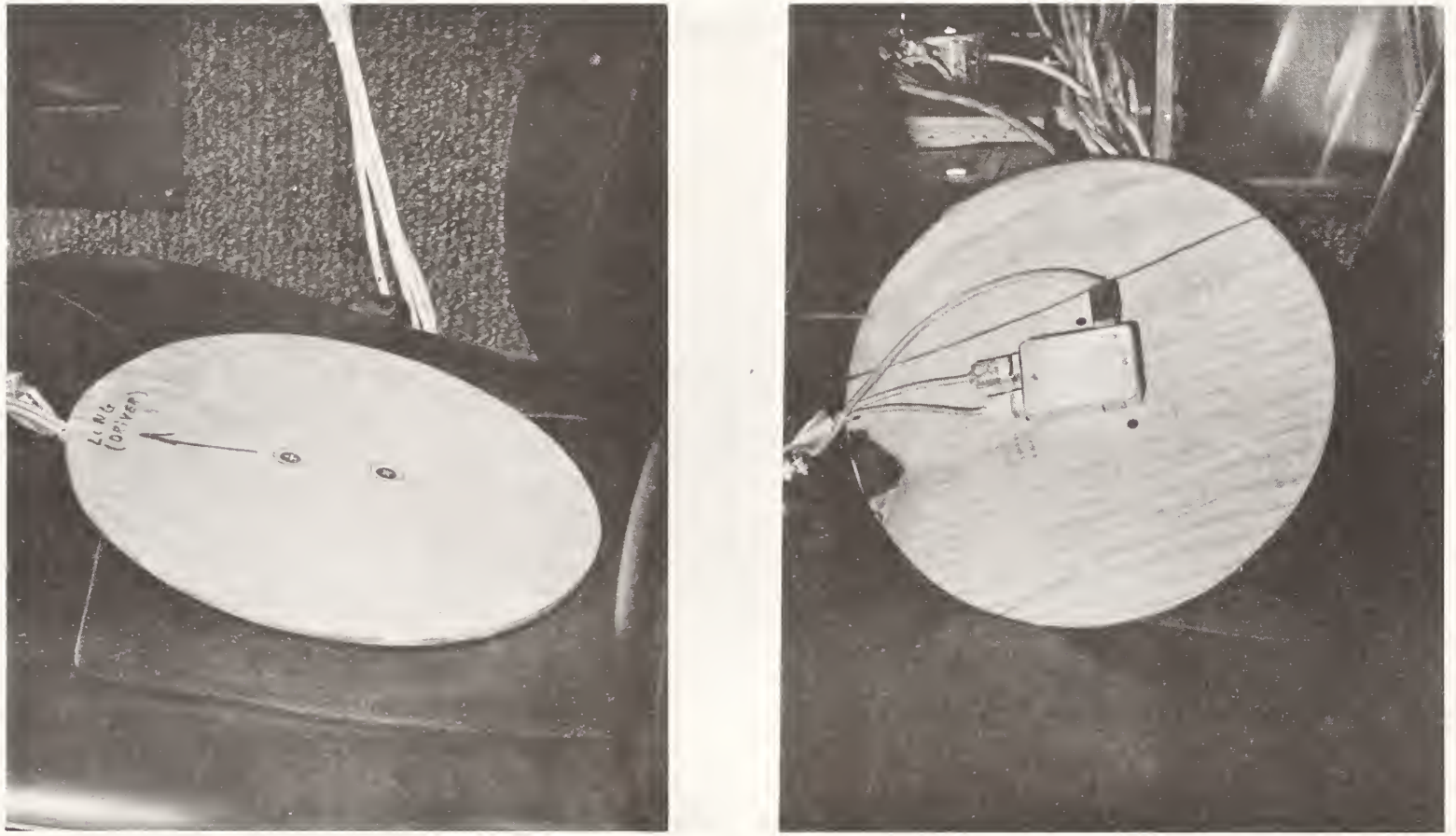


Figure 7. Instrumented Seat Disc for Measuring Vibration Input to a Seated Subject.

An event marker triggered by the driver upon starting and completing the test provided an impulse signal on the recording system.

A U-tube manometer, mounted on the vehicle in the driver's field of view, was used to monitor the vehicle acceleration during the urban driving test.

5.1.3 Calibration Procedures

The fifth wheel was calibrated daily using a calibration motor to spin the wheel. The tire pressure was adjusted to obtain the proper calibration values.

All accelerometers were calibrated in the Dynamic Science instrumentation laboratory before installation on each vehicle. The calibrations were performed according to standard industry practices using a shaker table and a standard accelerometer.

Pre- and post-test electrical calibrations of the instrumentation/data acquisition system were obtained for each set of test runs.

5.1.4 Data Acquisition

The data acquisition system is shown schematically in Figure 8. The on-board signal conditioning equipment amplified and multiplexed the instrumentation data, which were then transmitted to the Central Data Acquisition Control Station (CDACS) via a telemetry system. At the CDACS, the data were recorded on a tape recorder for a permanent record of the test as well as for access at a future date. The data were also discriminated and displayed on a recording oscillograph for the purpose of obtaining quick-look evaluation data. The quick-look data served to give a check as

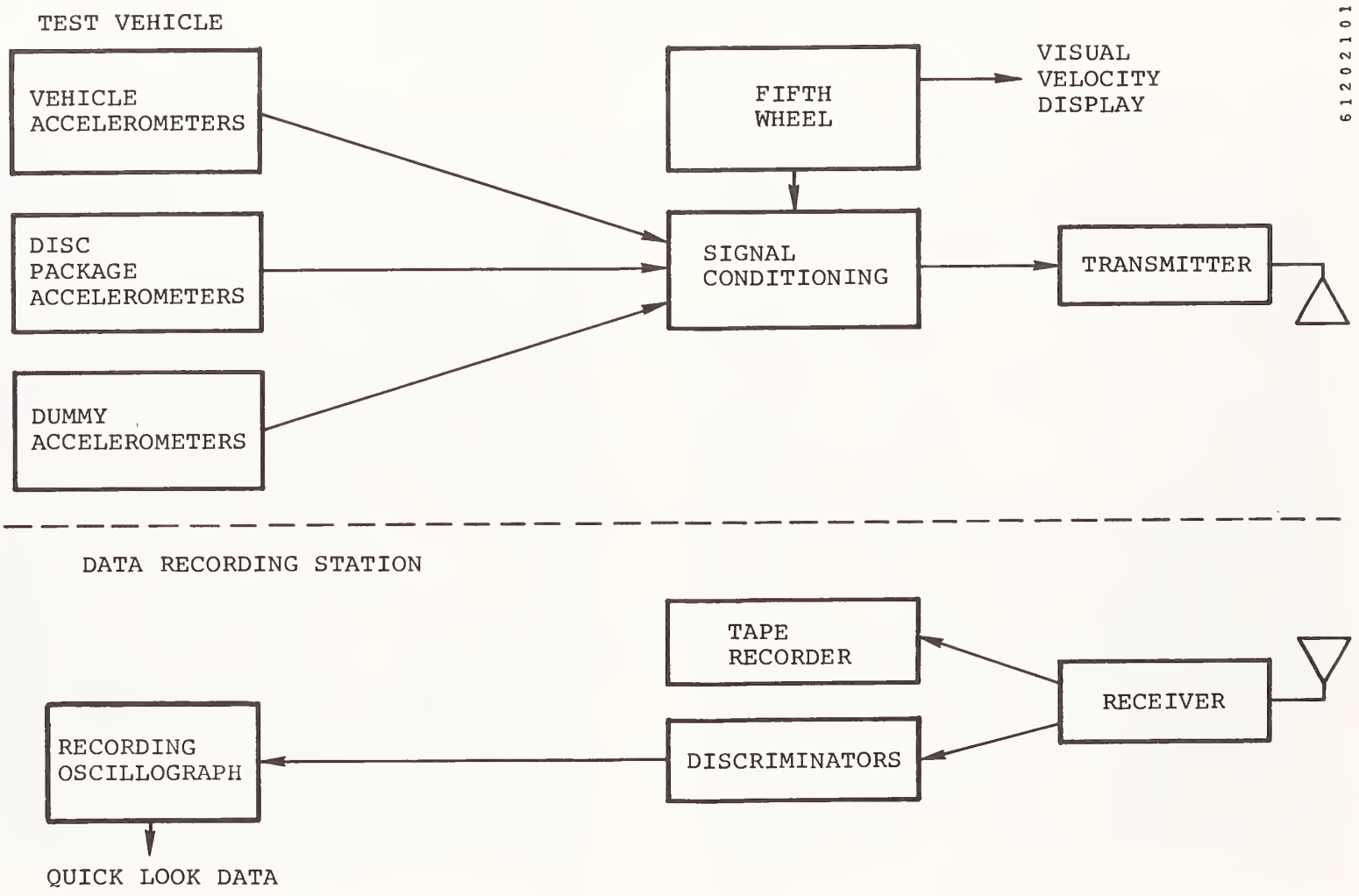


Figure 8. Data Acquisition System Schematic.

to whether test conditions had been achieved and also provided a view of the critical test parameters to ensure that good data were obtained during the test period.

The data recording started at least 20 seconds prior to entering the ride quality course or 20 seconds before starting the urban driving cycle and continued until at least 20 seconds after leaving the ride quality course or completing the urban driving cycle.

5.1.5 Data Reduction

Driver and passenger vertical accelerations and vehicle angular accelerations (roll rates) were analyzed in the 0.8 to 80 Hz range using a B & K Model 2131 spectrum analyzer. The rms accelerations were averaged over 1/3-octave increments, digitized, and computer plotted as power spectral density curves.

5.2 VEHICLE PREPARATION

The vehicles were prepared by installing the instrumentation listed in Table 5 and by loading to the prescribed passenger loading conditions listed in Table 4.

The Labeco fifth wheel was mounted to the rear bumper outboard of the vehicle to avoid the ride course obstacles. The installation on the Nova, shown in Figure 9, was typical of all the vehicles. The visual display for the fifth wheel, along with the manometer for the urban driving tests, were installed for easy viewing by the test driver as shown in Figure 10.

The vehicle accelerometers were rigidly attached to the vehicle structure, and the seat discs used to measure input vibration to the occupants were placed in position. The vibration coordinate system orientation for all the accelerometers is illustrated in Figure 11.

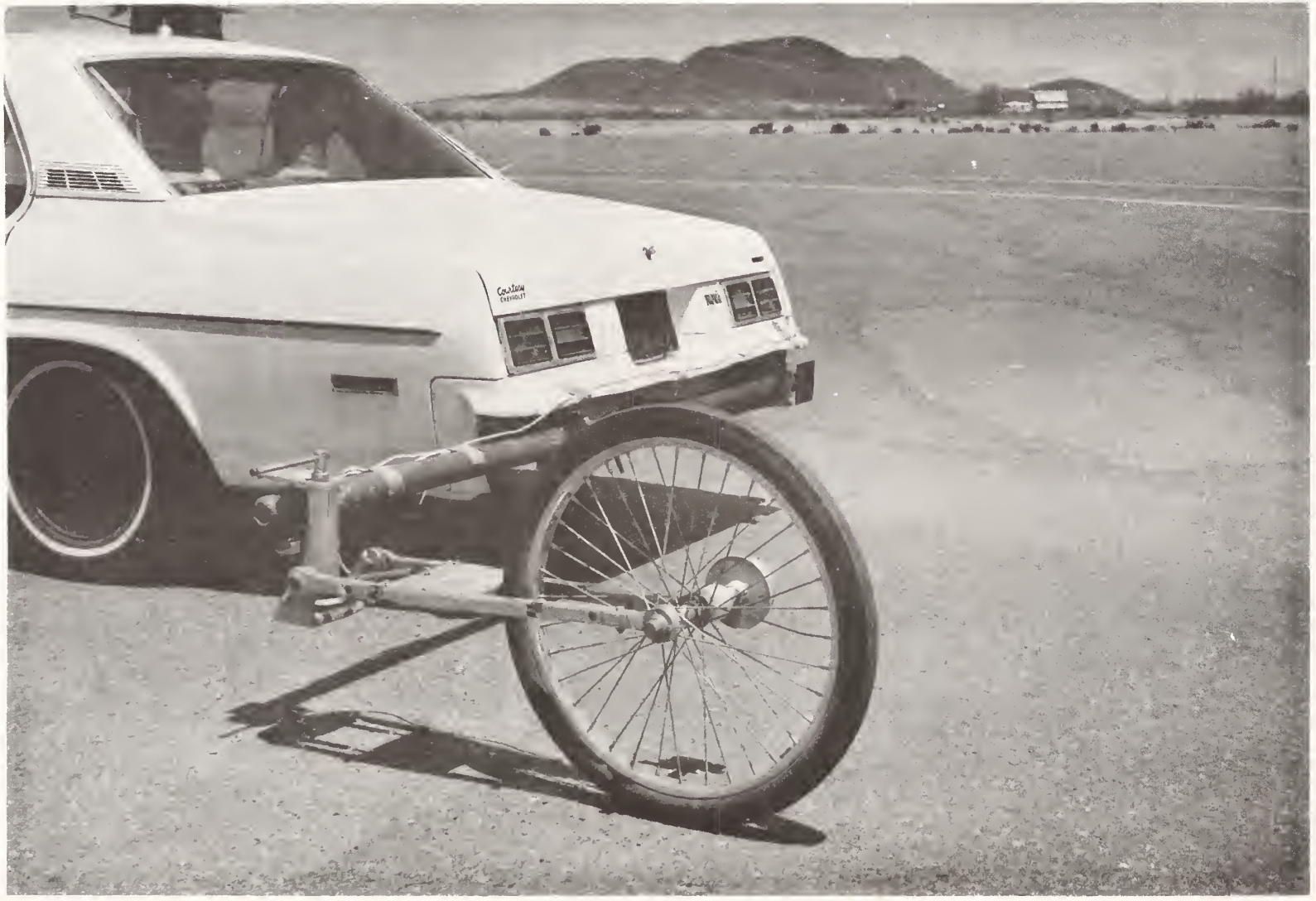


Figure 9. Typical Fifth Wheel Installation.

Figure 10. Manometer and Fifth Wheel Visual Display Installed in Dutcher Prototype.

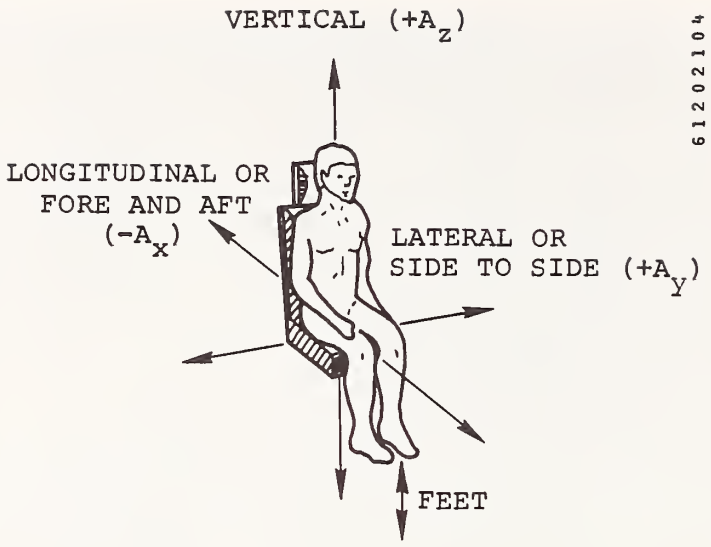


Figure 11. The Vibratory Coordinate System.

All passenger loading conditions were met by installing 50th percentile male dummies in the required seating positions. The wheelchair passengers in the ASL and Dutcher prototypes are shown in Figures 12 and 13, respectively. The vehicle test weights for the lightly loaded (driver and one passenger) and heavily loaded (driver and three passengers) conditions are given in Table 6.

5.3 TEST CONDUCT

5.3.1 General Test Conditions

A test was repeated if the specified test speeds were not met or maintained sufficiently throughout the test. The specifications on the ride course test speed were ±2 mph on initial speed and ±5 mph during the test. The specification for the urban driving test was ±2 mph throughout the test. As an added check on test speed, the elapsed time of each test was recorded and compared with the specifications listed in Table 7.

Figure 12 Wheelchair Passenger in ASL Prototype.

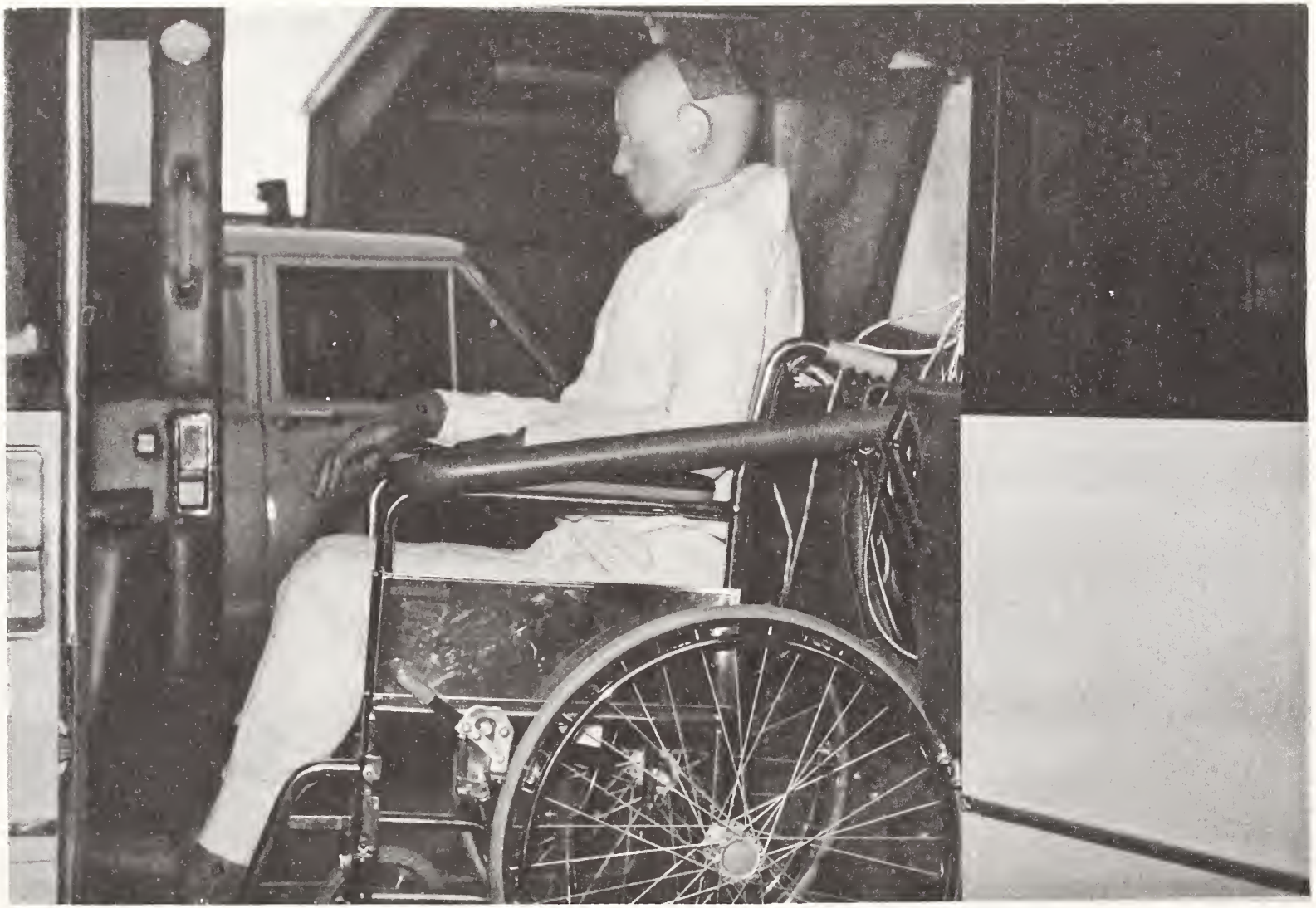


Figure 13. Wheelchair Passenger in Dutcher Prototype.

TABLE 6. VEHICLE TEST WEIGHTS

Vehicle	Test Weight (lb) Lightly Loaded (Driver + 1 Passenger)	Heavily Loaded (Driver + 3 Passengers)
Nova (Baseline)	3896	4229
ASL Prototype	3949 (urban driving course)	4236*
	3915 (ride quality course)*	
Dutcher Prototype	3460	3817

*Catalytic converter and exhaust pipe removed to prevent bottoming on ride course (see Section 5.4 of text).

TABLE 7. TEST DURATION SPECIFICATIONS

Course	Test Speed (mph)	Course Length (ft)	Test Duration (sec)
Ride	5	1,000	136 ±14
Ride	10	1,000	68 ±7
Ride	20	775	26 ±2
Ride	30	775	18 ±2
Ride	40	775	13 ±1
Urban	15.6 average	10,560	461 ±20

In addition, vehicle acceleration/deceleration during the urban driving test had to be maintained within ±2 ft/sec^2 of the specified values.

5.3.2 Ride Quality Tests

The ride quality tests were conducted by driving the vehicle over the appropriate part of the ride course at the desired test speed so that the vehicle encountered every obstacle in the course. For the 5- and 10-mph tests, the first 1000 feet of the ride course were utilized (see Figure 6). For tests of 20 mph or more, the last 775 feet of the course were used. Figures 14 and 15 show the Dutcher and ASL prototypes, respectively, driving over the 2-inch-deep chuckholes.

5.3.3 Urban Driving Tests

The urban driving tests were conducted according to Table 8.

5.4 PROBLEMS ENCOUNTERED DURING TESTING

The ASL prototype bottomed out during the 10-mph test in the lightly loaded condition and during the 5-mph test in the heavily loaded condition. An examination of the vehicle showed that the catalytic converter was striking the ground due to the low ground clearance of the vehicle as a whole (see Figure 15). The damage to the converter is shown in Figures 16 and 17.

The catalytic converter and exhaust pipe were removed from the vehicle to eliminate the problem, and testing was then continued. Even with the modification, however, the rubber grommets and wires were scraped off the electric ramp motors during the 30-mph test in the heavily loaded condition, as shown in Figure 18.

The suspension on the Dutcher prototype was reset by the manufacturer before the ride testing began, to give a ground clearance of 8-1/2 inches. This was sufficient to prevent the Dutcher from bottoming out during any of the tests.

Figure 14. Dutcher Prototype Driving Over 2-Inch-Deep Chuckholes.

Figure 15. ASL Prototype Driving Over 2-Inch Deep Chuckholes.

TABLE 8. URBAN DRIVING COURSE

Distance (miles)	Operation
0.0	Engage event switch and start timing device, idle 15 sec, accelerate to 15 mph at 7 ft/sec^2. Proceed at 15 mph to the 0.2 mile marker.
0.2	Stop at 4 ft/sec^2, accelerate to 15 mph at 7 ft/sec^2. Proceed at 15 mph to the 0.3 mile marker.
0.3	Decelerate to 5 mph at 4 ft/sec^2, accelerate to 15 mph at 7 ft/sec^2. Proceed at 15 mph to the 0.5 mile marker.
0.5	Stop at 4 ft/sec^2, idle 15 sec, accelerate to 20 mph at 7 ft/sec^2. Proceed at 20 mph to the 0.7 mile marker.
0.7	Stop at 4 ft/sec^2, accelerate to 20 mph at 7 ft/sec^2. Proceed at 20 mph to the 0.8 mile marker.
0.8	Decelerate to 10 mph at 4 ft/sec^2, accelerate to 20 mph at 5 ft/sec^2. Proceed at 20 mph to the 1.0 mile marker.
1.0	Stop at 4 ft/sec^2, idle 15 sec, accelerate at 15 mph at 7 ft/sec^2, then to 25 mph at 5 ft/sec^2. Proceed at 25 mph to the 1.2 mile marker.
1.2	Stop at 4 ft/sec^2, accelerate to 15 mph at 7 ft/sec^2, then to 25 mph at 5 ft/sec^2. Proceed at 25 mph to the 1.3 mile marker.
1.3	Decelerate to 15 mph at 4 ft/sec^2, accelerate to 25 mph at 5 ft/sec^2. Proceed at 25 mph to the 1.5 mile marker.
1.5	Stop at 4 ft/sec^2, idle 15 sec, accelerate to 15 mph at 7 ft/sec^2, then to 30 mph at 5 ft/sec^2. Proceed at 30 mph to the 1.7 mile marker.
1.7	Stop at 4 ft/sec^2, accelerate to 15 mph at 7 ft/sec^2, and then to 30 mph at 5 ft/sec^2. Proceed at 30 mph to the 1.8 mile marker.
1.8	Decelerate to 20 mph at 4 ft/sec^2, accelerate to 30 mph at 5 ft/sec^2. Proceed at 30 mph.
2.0	Begin braking at 4 ft/sec^2 to arrive at stop at 2.0 mile marker. Stop timing device and disengage event switch.

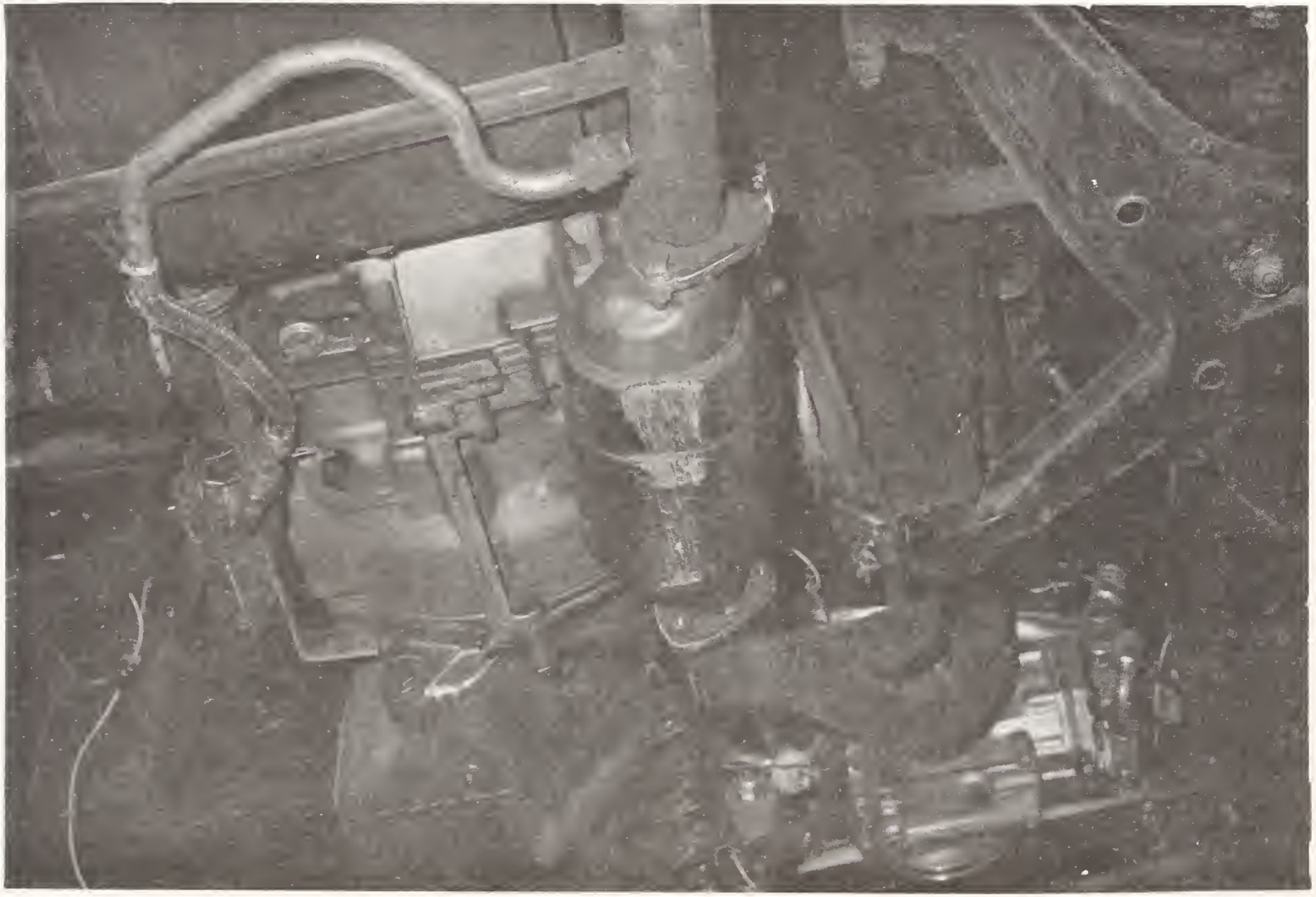


Figure 16. Damage to ASL Catalytic Converter Incurred During Ride Tests.

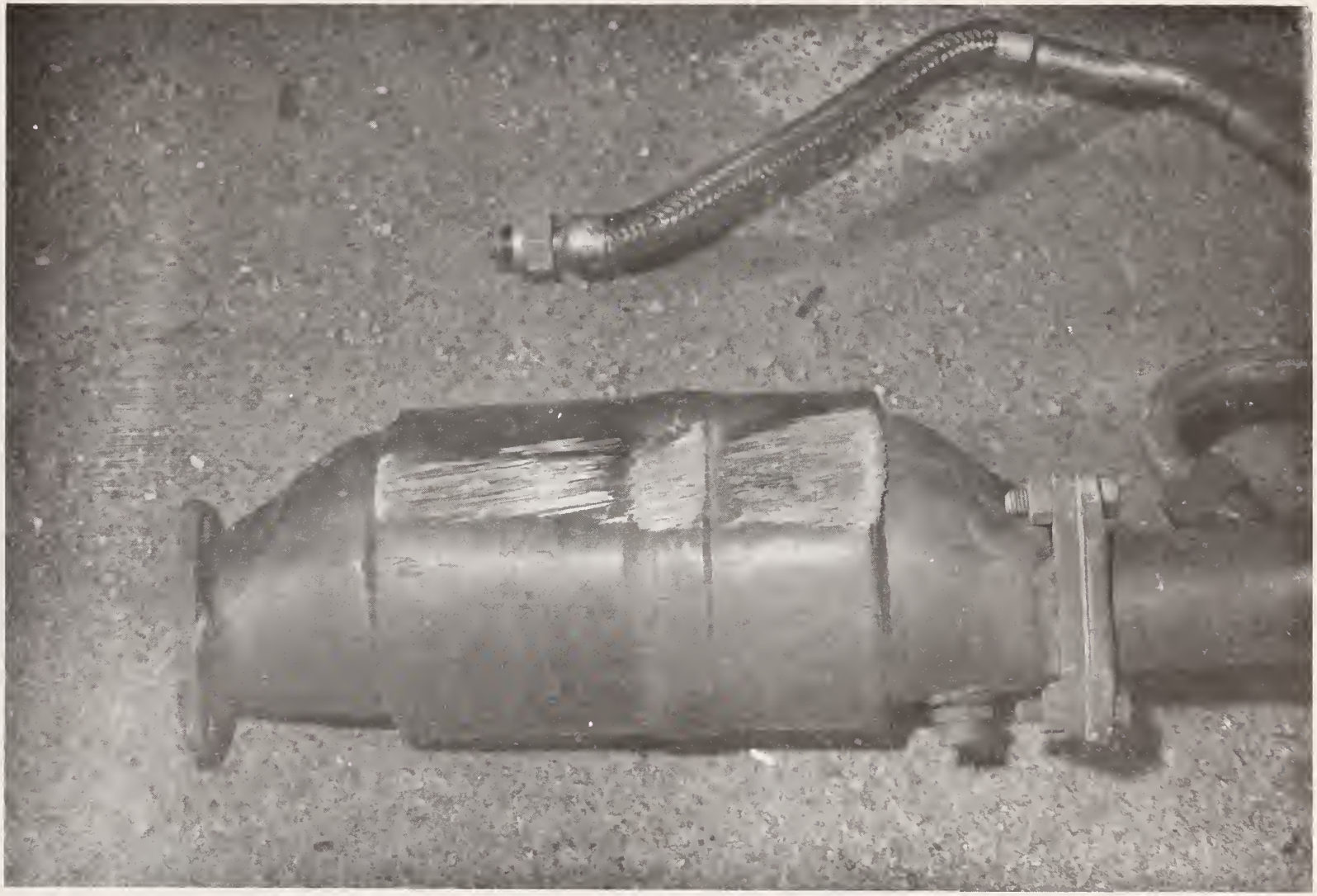


Figure 17. ASL Catalytic Converter After Removal From Vehicle.

Figure 18. Damage to ASL Electric Ramp Motor Incurred During Ride Tests.

6.0 TEST RESULTS

6.1 RMS ACCELERATION VERSUS FREQUENCY

RMS vertical accelerations versus frequency were plotted for each occupant position. These plots are contained in Appendices B, C, and D.

The acceleration versus frequency curves were compared with exposure limit boundaries contained in International Standard ISO 2631, "Guide for the Evaluation of Human Exposure to Whole-Body Vibration." The boundaries of interest for this test program were the "reduced comfort boundary" for the passengers and the "fatigue decreased proficiency boundary" for the driver. These boundaries are dependent on exposure time and are shown in Figure 19.

The vibration exposure limits corresponding to 16 minutes were used for evaluation of the baseline and paratransit vehicles. This exposure time selection was based on studies of the average taxi ride duration in New York and Chicago.* These driver and passenger limits are shown in Figure 20.

None of the vehicles exceeded the fatigue decreased proficiency boundary for the driver during any of the tests. All of the vehicles, however, exceeded the reduced comfort boundary for the passengers during some of the tests.

The performance of the vehicles with respect to the passenger comfort limit is summarized in Table 9. The Dutcher prototype had the best performance of all three vehicles, exceeding the limit by only a small amount during the 10-mph ride tests in the lightly loaded condition (1 passenger). The Nova

*Kirby, R. F., et al., "Para-Transit Neglected Options for Urban Mobility," The Urban Institute, 1974.

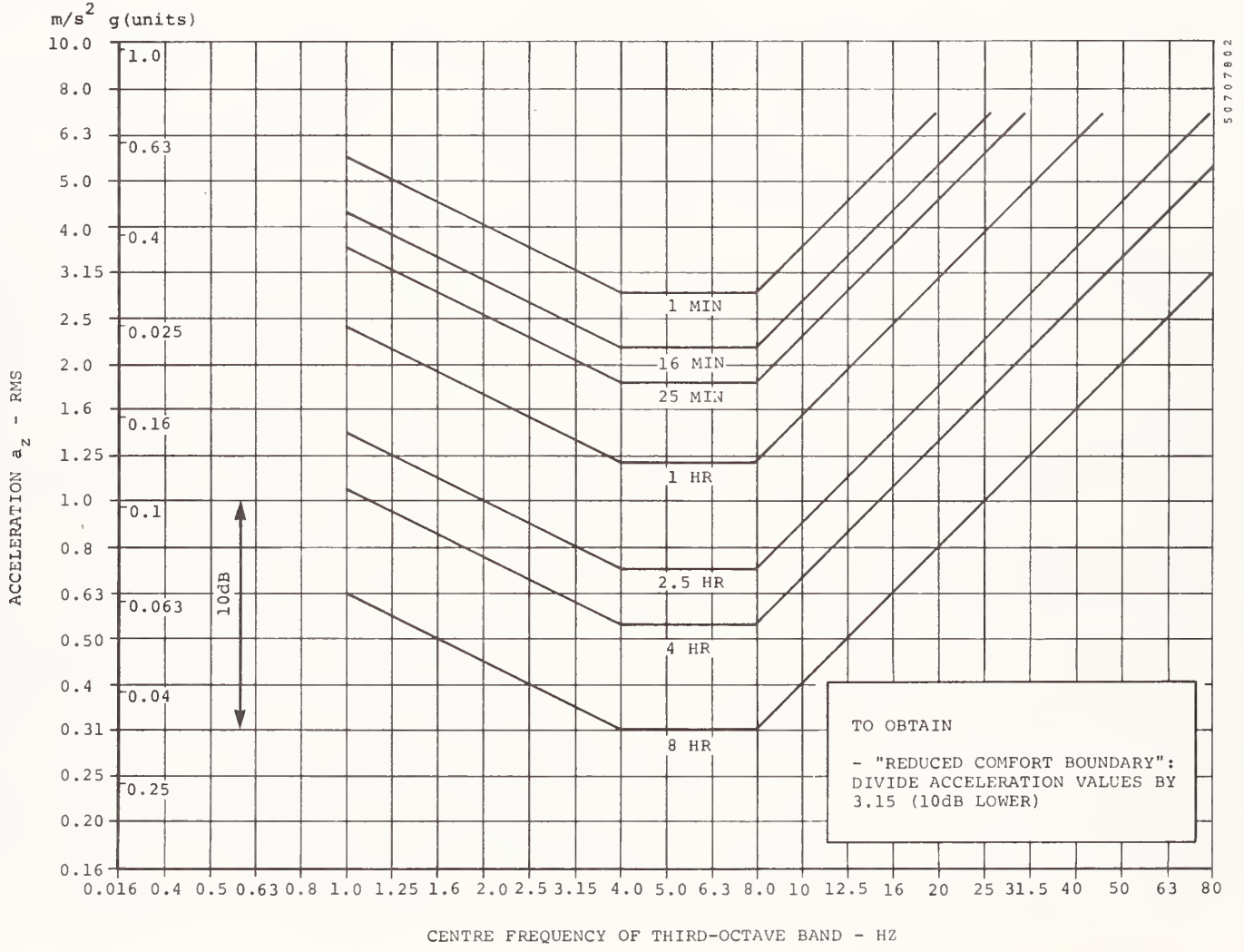


Figure 19. Vertical (a_z) Vibration Exposure Limits as a Function of Frequency and Exposure Time; "Fatigue-Decreased Proficiency Boundary."

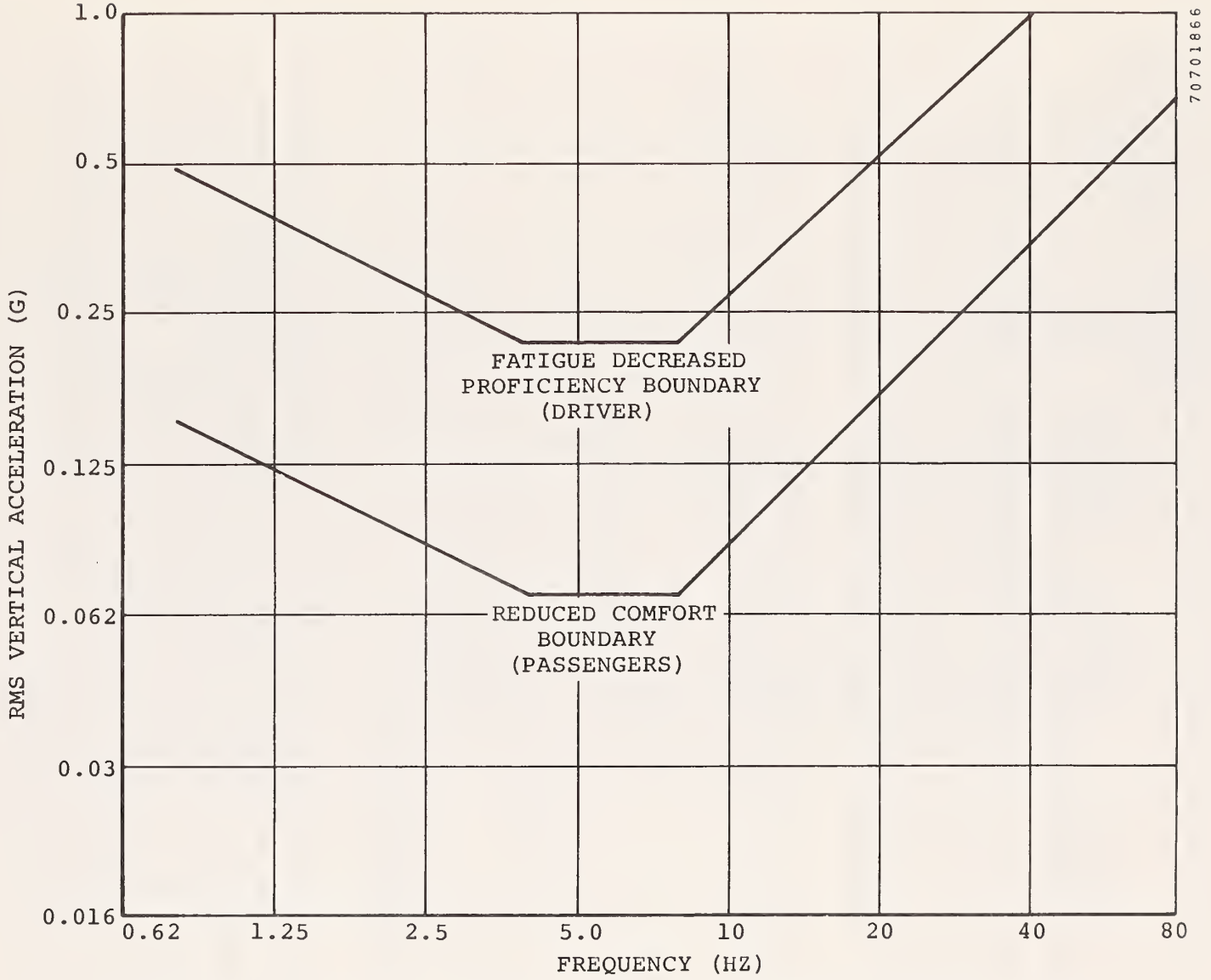


Figure 20. Vertical Vibration Limits for 16 Minutes Exposure Time.

TABLE 9. TESTS EXCEEDING PASSENGER REDUCED COMFORT BOUNDARY.*

Vehicle	Test Condition	Passenger Location	Frequency at Which Excess Occurred (Hz)	Amount of Excess - RMS Acceleration (G)
Nova (Baseline)	Light Load, 10 mph	Rear Seat	4.0	0.05
Nova	Heavy Load, 5 mph	Rear Seat	2.0	0.01
Nova	Heavy Load, 10 mph	Rear Seat	3.2; 4.0	0.04; 0.02
ASL Prototype	Light Load, 10 mph	Wheelchair	4.0	0.01
ASL	Light Load, 5 mph	Rear Seat	2.0	0.01
ASL	Light Load, 10 mph	Rear Seat	4.0	0.02
ASL	Heavy Load, 5 mph	Rear Seat	1.6	0.06
ASL	Heavy Load, 10 mph	Rear Seat	4.0	0.04
Dutcher Prototype	Light Load, 10 mph	Wheelchair	3.2	0.01
Dutcher	Light Load, 10 mph	Rear Seat	4.0	0.01

*As defined in ISO 2631.

baseline vehicle exceeded the limit significantly during the 10-mph tests in both the lightly and heavily loaded condition (3 passengers). The ASL prototype also exceeded the limit significantly during the 5- and 10-mph tests in the heavily loaded condition, but only with the rear seat occupant. This is typical of the ASL performance throughout the test series, i.e. the rear seat passenger accelerations were generally higher than those of the wheelchair passenger.

6.2 OVERALL WEIGHTED VIBRATION VERSUS VEHICLE VELOCITY

A single vibration quantity for each vehicle for each test condition can be obtained by using the overall weighted vibration level as defined in ISO 2631.

An overall weighted vibration level is the root-mean-squared of the weighted acceleration for the particular test condition. The weighting is obtained by dividing the vibration acceleration by the appropriate exposure limit boundary. The weighting factor is normalized so that it has a value of 1 for the 4 to 8 Hz band for vertical acceleration measurements, as shown in Table 10.

The overall weighted acceleration is determined by summing the weighted accelerations over the frequency range 0 to 80 Hz according to the following formula:

$$A_W = \frac{1}{F} \int_0^{80} a_i \, w_i \, df_i$$

where A_w - overall weighted acceleration - G

F = total frequency range = 80 Hz

i = 1/3-octave band

a_i = acceleration at 1/3-octave band

w_i = weighting factor for 1/3-octave band

f_i = center frequency of 1/3-octave band

TABLE 10. WEIGHTING FACTORS FOR VERTICAL ACCELERATIONS (FROM ISO 2631).

Frequency (center frequency of third octave band) (Hz)	Weighting Factor
1.0	0.50 = -6dB
1.25	0.56 = -5dB
1.6	0.63 = -4dB
2.0	0.71 = -3dB
2.5	0.80 = -2dB
3.15	0.90 = -1dB
4.0	1.00 = 0dB
5.0	1.00 = 0dB
6.3	1.00 = 0dB
8.0	1.00 = 0dB
10.0	0.80 = -2dB
12.5	0.63 = -4dB
16.0	0.50 = -6dB
20.0	0.40 = -8dB
25.0	0.315 = -10dB
31.5	0.25 = -12dB
40.0	0.20 = -14dB
50.0	0.16 = -16dB
63.0	0.125 = -18dB
80.0	0.10 - -20dB

The overall weighted vibration level allows a direct comparison to be made between the occupants of the three vehicles. The overall weighted acceleration transmitted for the drivers versus vehicle velocity for the three different loading conditions are presented in Figures 21, 22, and 23. These figures show that the Nova driver had the lowest overall vibration level during all of the ride quality tests, followed by the ASL and the Dutcher in all tests but one. The higher overall acceleration for the ASL driver shown in Figure 21 was caused by the presence of vibrations at higher-than-normal frequencies (up to 63 Hz) during the 10-mph test. These high-frequency vibrations were probably caused by the slight bottoming of the vehicle as it drove over the 2-inch chuckholes.

The overall weighted accelerations transmitted to the passengers are shown in Figures 24, 25, and 26. Although some slight variations exist, the Dutcher generally showed the lowest vibration levels for the passengers in the lightly loaded condition, followed by the ASL and the Nova (Figures 24 and 25). The ASL wheelchair passenger showed high vibration levels during the 10-mph test in which the vehicle bottomed. As with the driver in this same test, some high-frequency vibrations were present. However, the acceleration levels in the critical 4 to 8 Hz range were also very close to the comfort boundary limit and thus contributed significantly to the higher overall weighted acceleration.

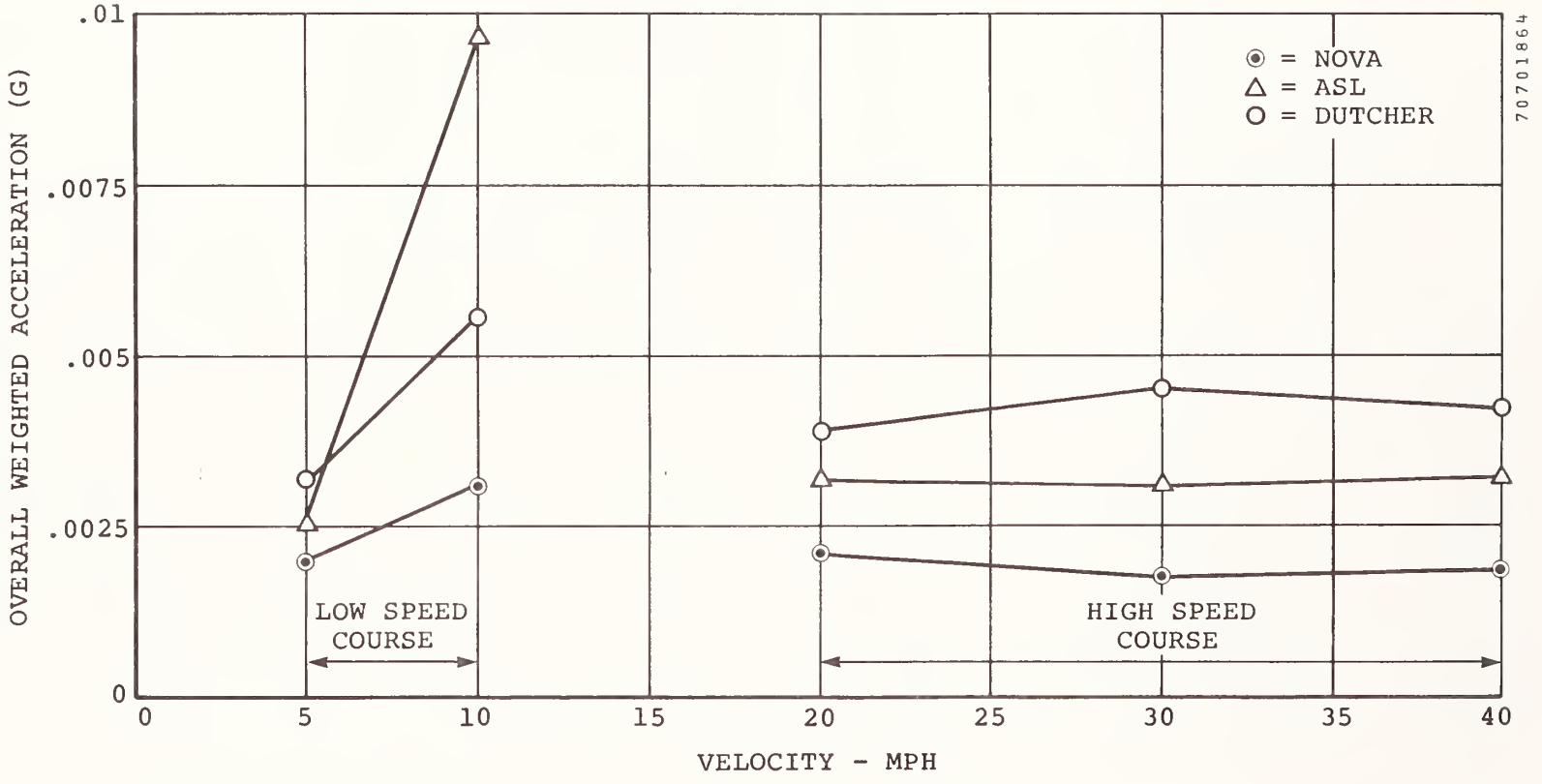


Figure 21. Overall Weighted Acceleration of Drivers, Light Load (One Passenger; Rear Seat - Nova, Wheelchair-PTV).

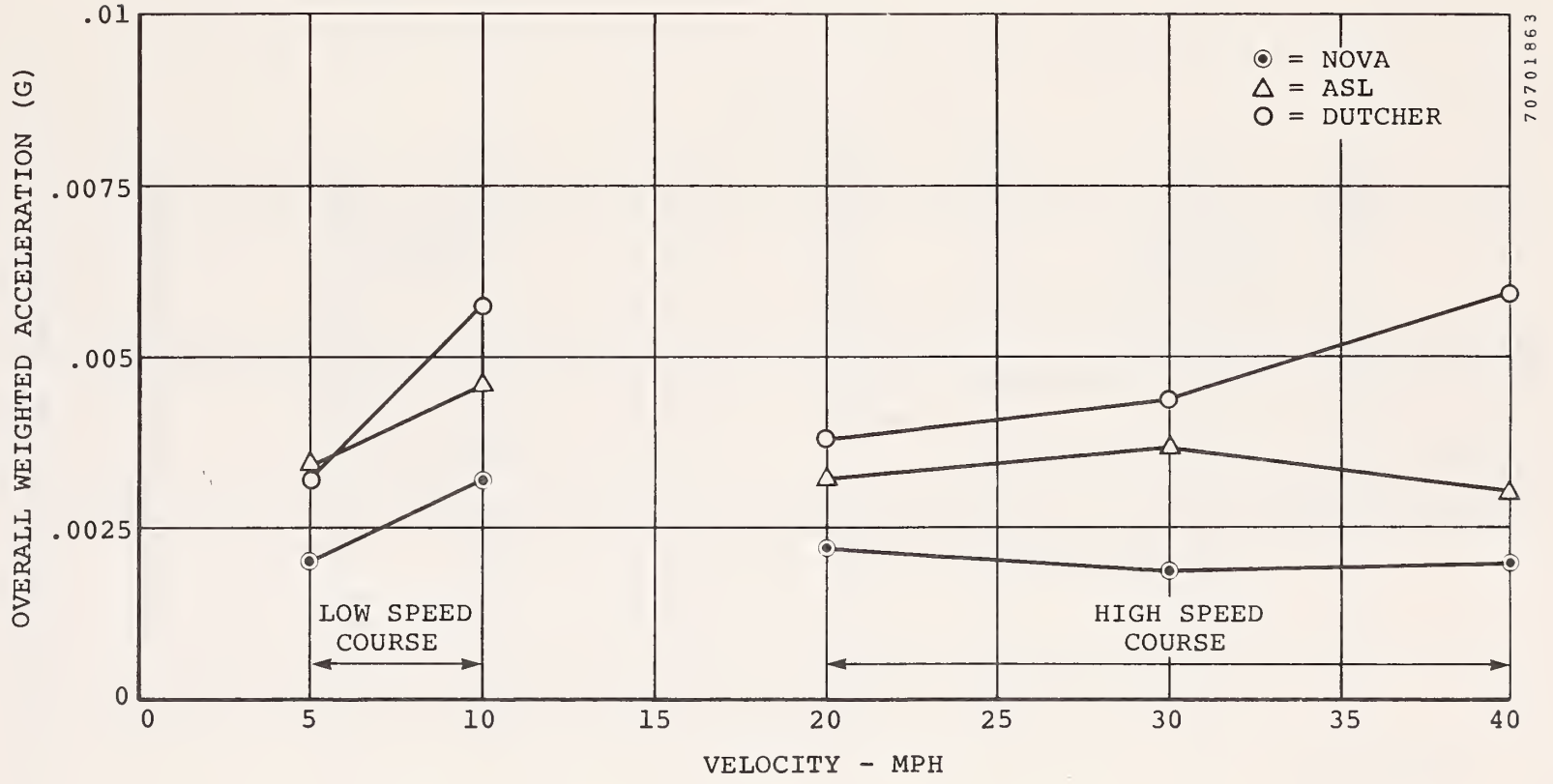


Figure 22. Overall Weighted Acceleration of Drivers, Light Load (One Rear Seat Passenger).

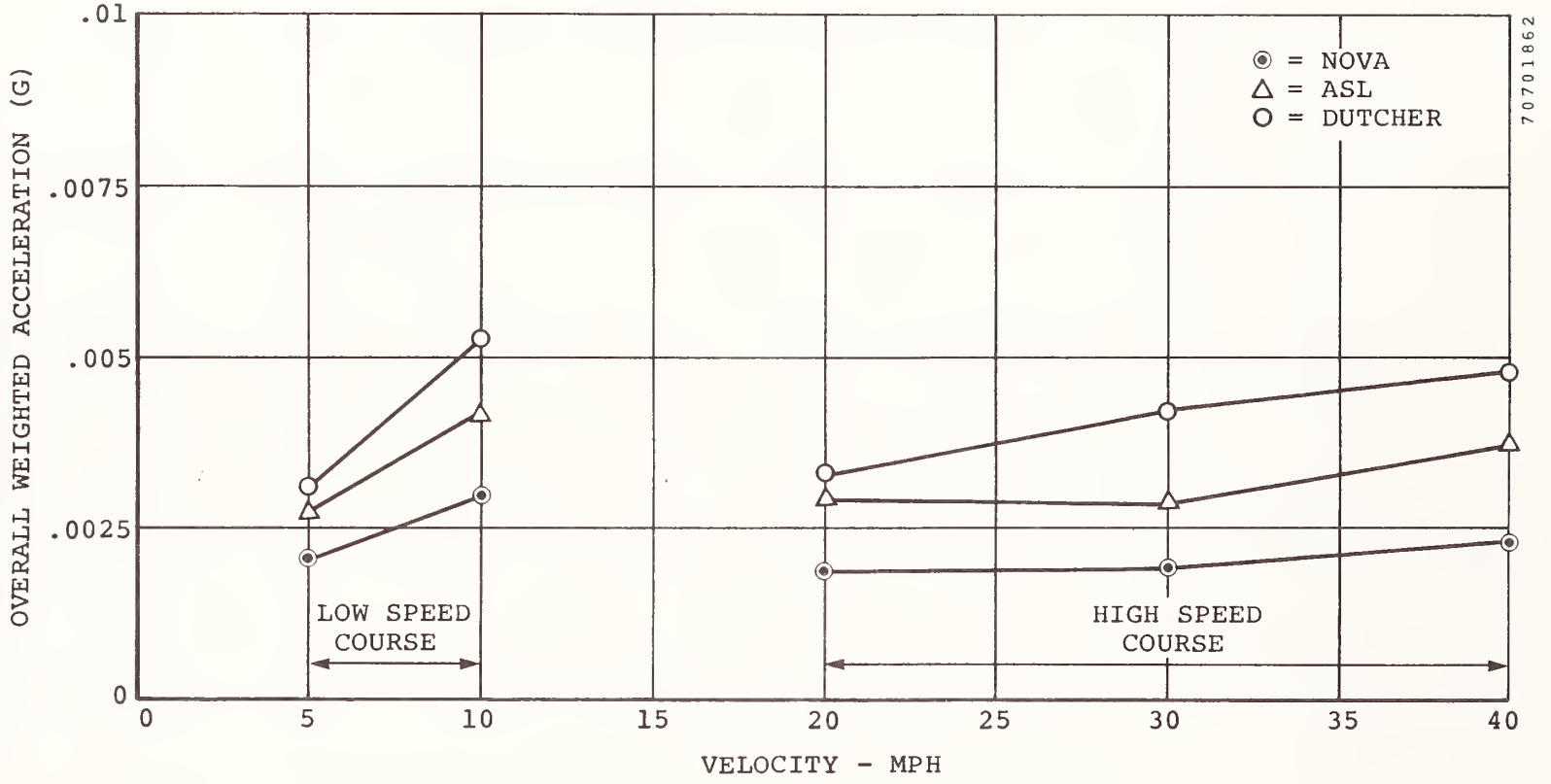


Figure 23. Overall Weighted Acceleration of Drivers, Heavy Load (3 Passengers).

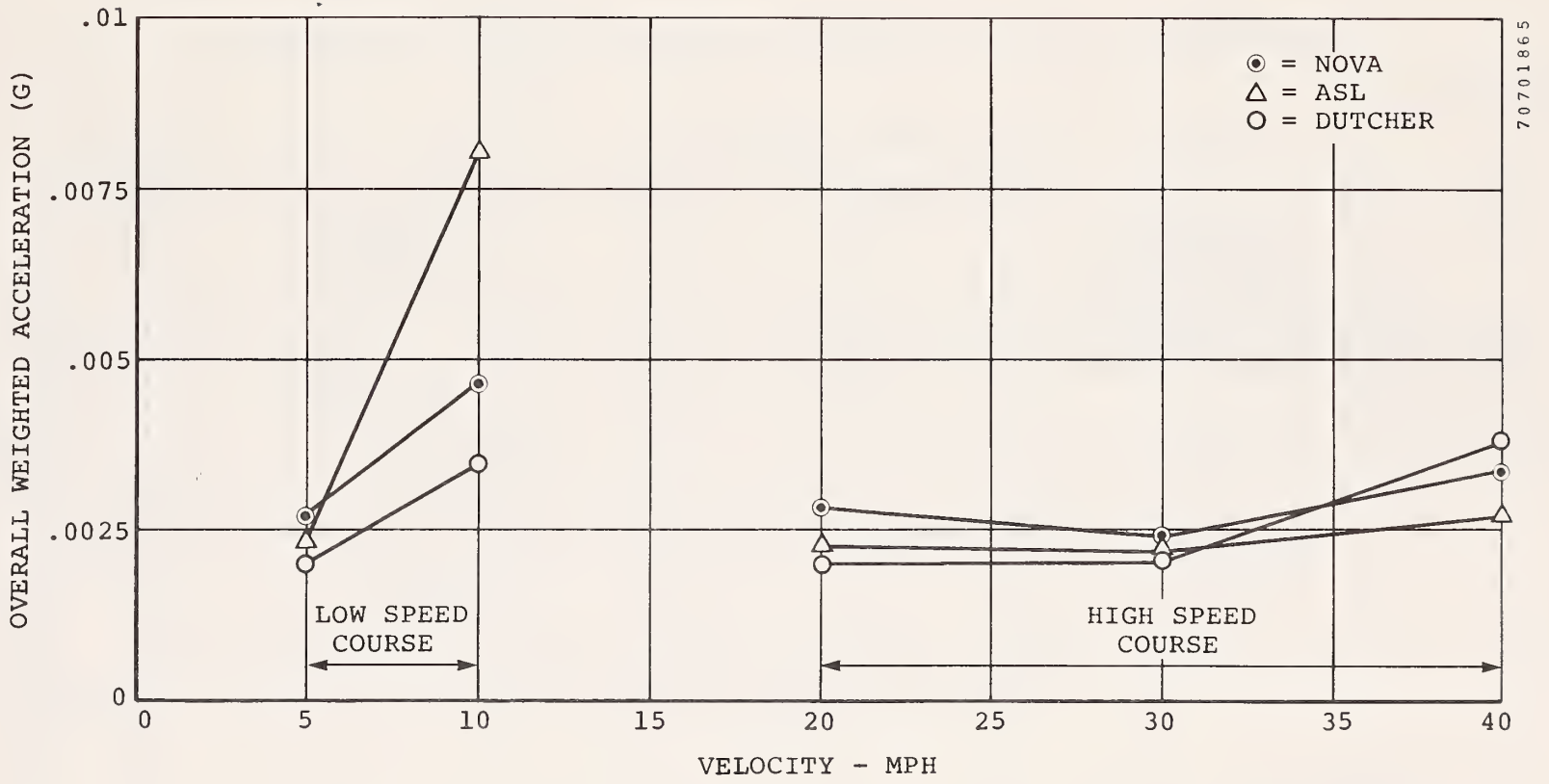


Figure 24. Overall Weighted Acceleration of Rear Seat Passenger (Nova) and Wheelchair Passengers (PTV), Light Load.

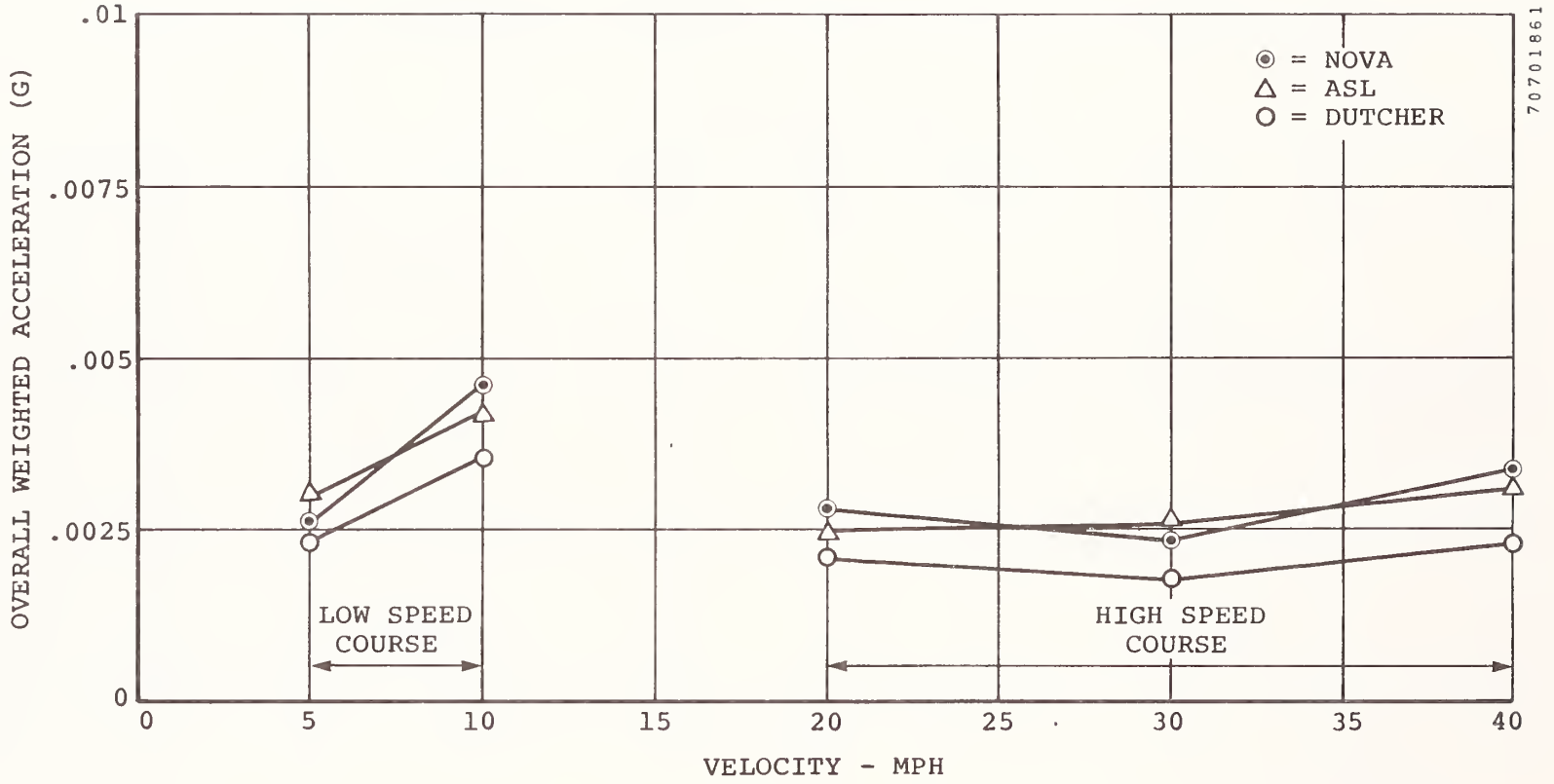


Figure 25. Overall Weighted Acceleration of Rear Seat Passengers, Light Load.

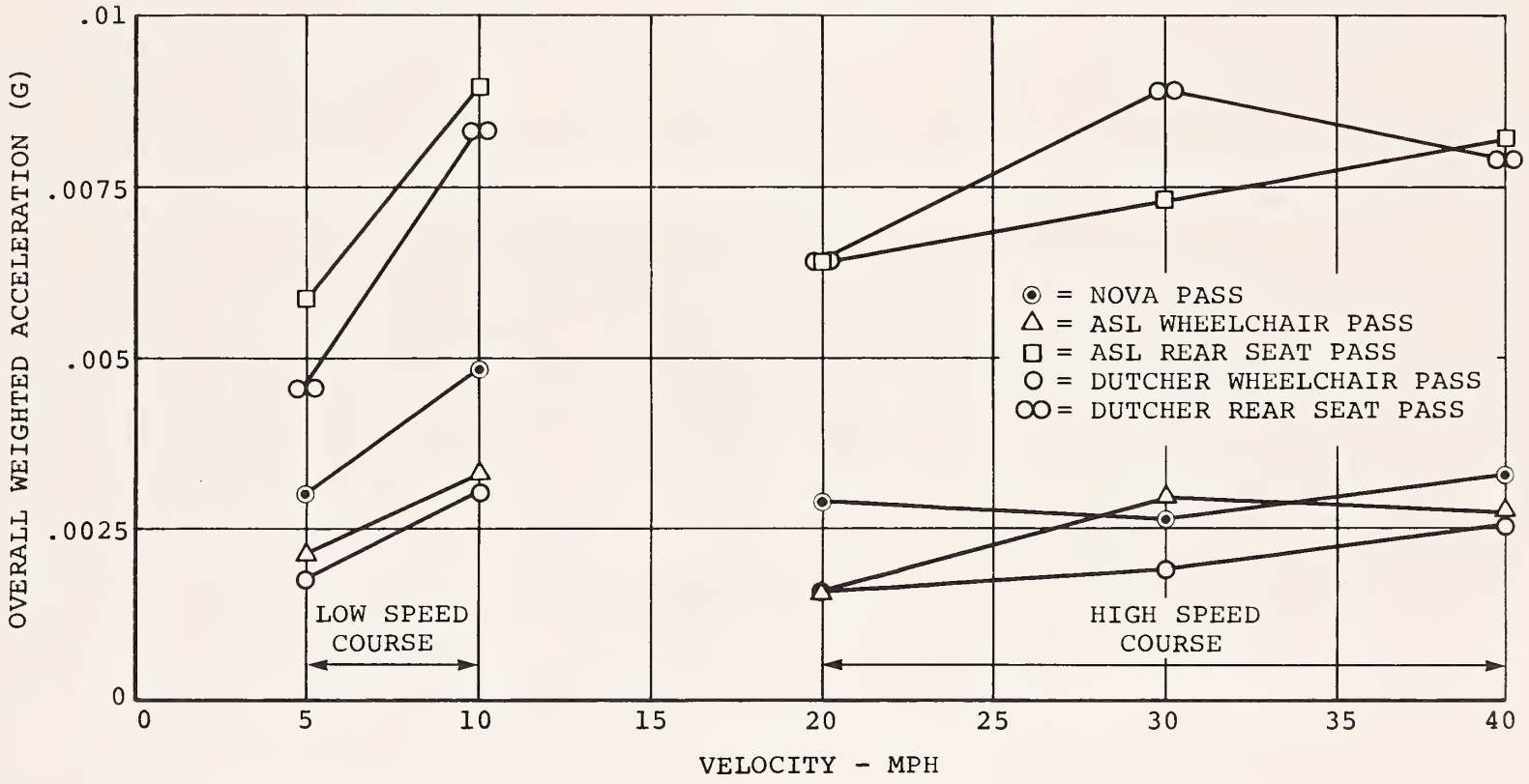


Figure 26. Overall Weighted Acceleration of Passengers, Heavy Load.

APPENDIX A

DESCRIPTION OF
RIDE QUALITY COURSE

The Dynamic Science ride quality course was designed to represent a spectrum of conditions, including some of the worst case conditions that might exist on city streets and highways, and is based on measurements of real roads.

A variety of obstacles are incorporated into a 12-foot wide, 1,700-foot long course. An additional 250 feet of smooth roadway is provided at the beginning and end of the course to allow undisturbed run-in and run-out during testing. Sections between obstacles consist of smooth roadway to allow the vehicle system to damp out between obstacles. The types of obstacles, the order of their occurrence, and their position on the course (in terms of course station in feet) are presented in Table A-1. An aerial view of the course is shown in Figure A-1.

A profile of the ride course as it was configured for the PTV tests is presented in Figure A-2. Only two of the three-inch deep chuckholes were used during these tests. Three-quarter-inch high tar strip simulators were used in the tie-down area. Photographs of each of the ride course obstacles are presented in Figures A-3 through A-8.

TABLE A-1. RIDE COURSE OBSTACLE LAYOUT

Course Station (ft)	Obstacle	Course Station (ft)	Obstacle	Course Station (ft)	Obstacle
0-75	2-inch deep random chuck-holes	625	2-inch deep perpendicular dip (2 feet wide)	925-1000	1-inch deep random chuck-holes
175-250	3-inch deep random chuck-holes	725	2-inch deep 27-degree oblique dip (2 feet wide)	1200-1400	Tie-down area (2-inch bumps for low-speed tests or 3/4-inch high freeway tar strip simulators for high-speed tests)
350-425	Sine wave generator 92-inch amplitude with a 4-foot wave length)	825	2-inch deep dip (right side only)		
525	Railroad crossing			1650-1700	High crown to high crown intersection

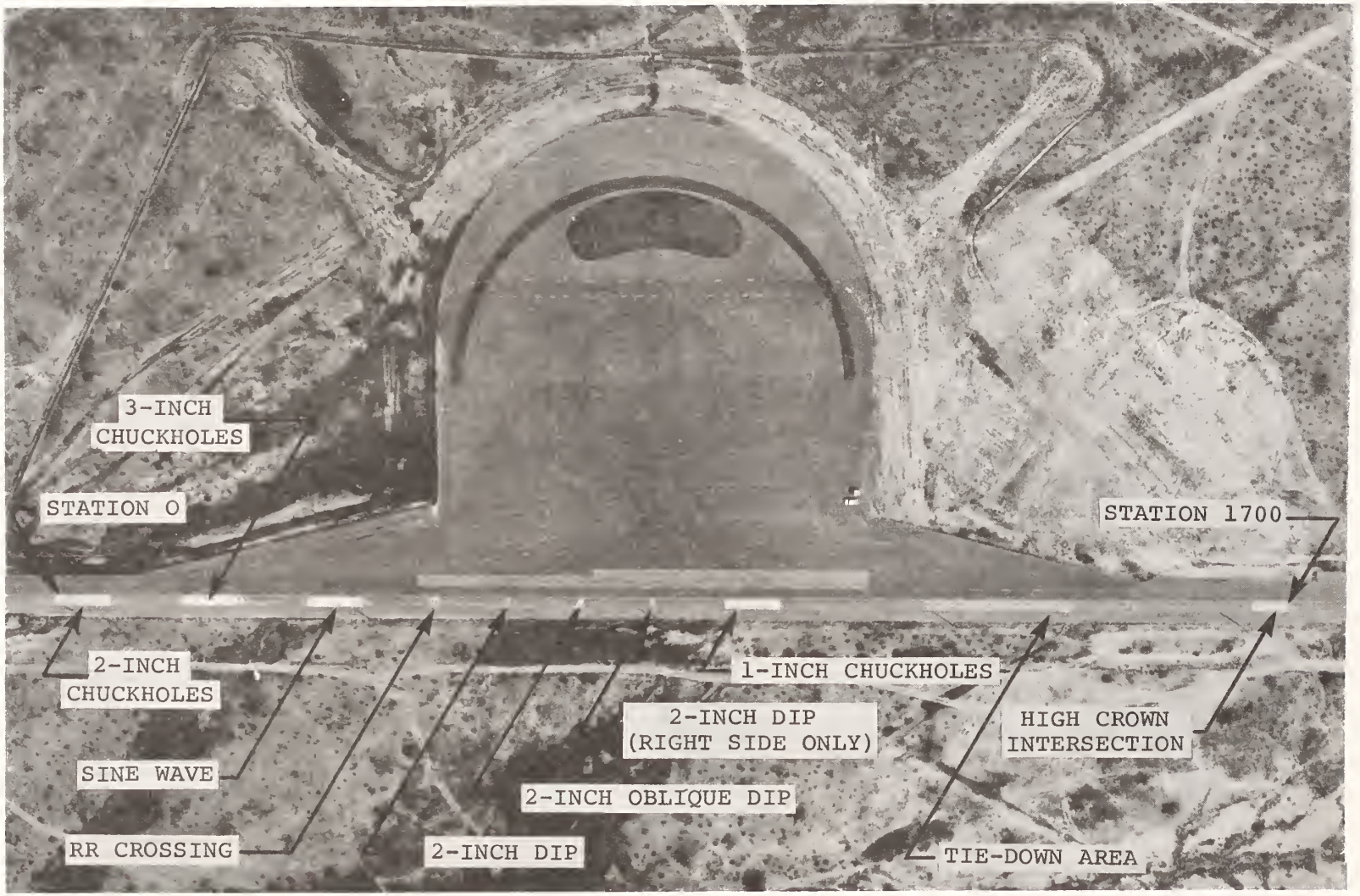


Figure A-1. Aerial View of Dynamic Science Ride Quality Course.

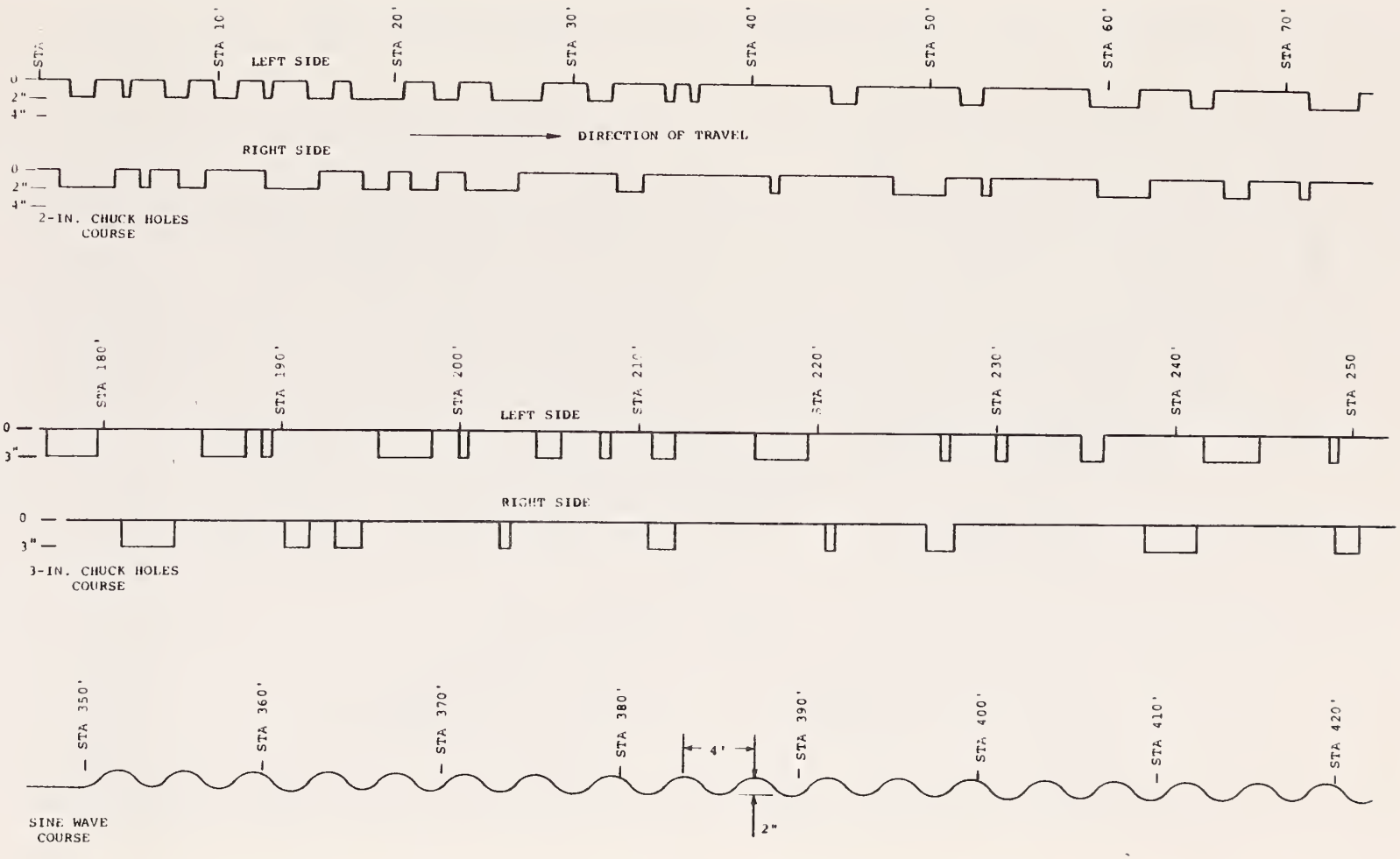


Figure A-2a. Ride Course Profile - Station Numbers 0 to 420 Inclusive.

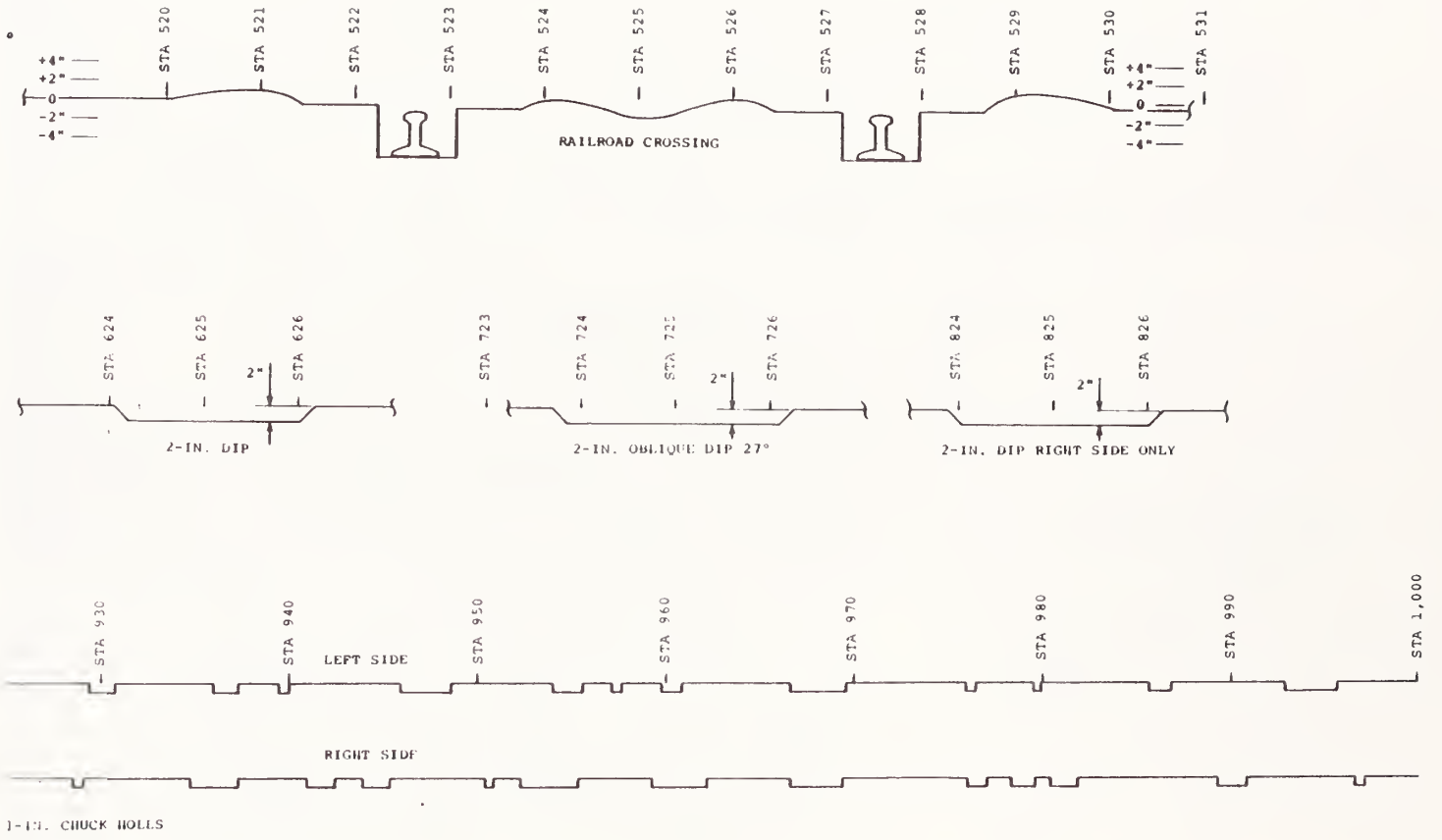


Figure A-2b. Ride Course Profile - Station Numbers 520 to 1,000 Inclusive.

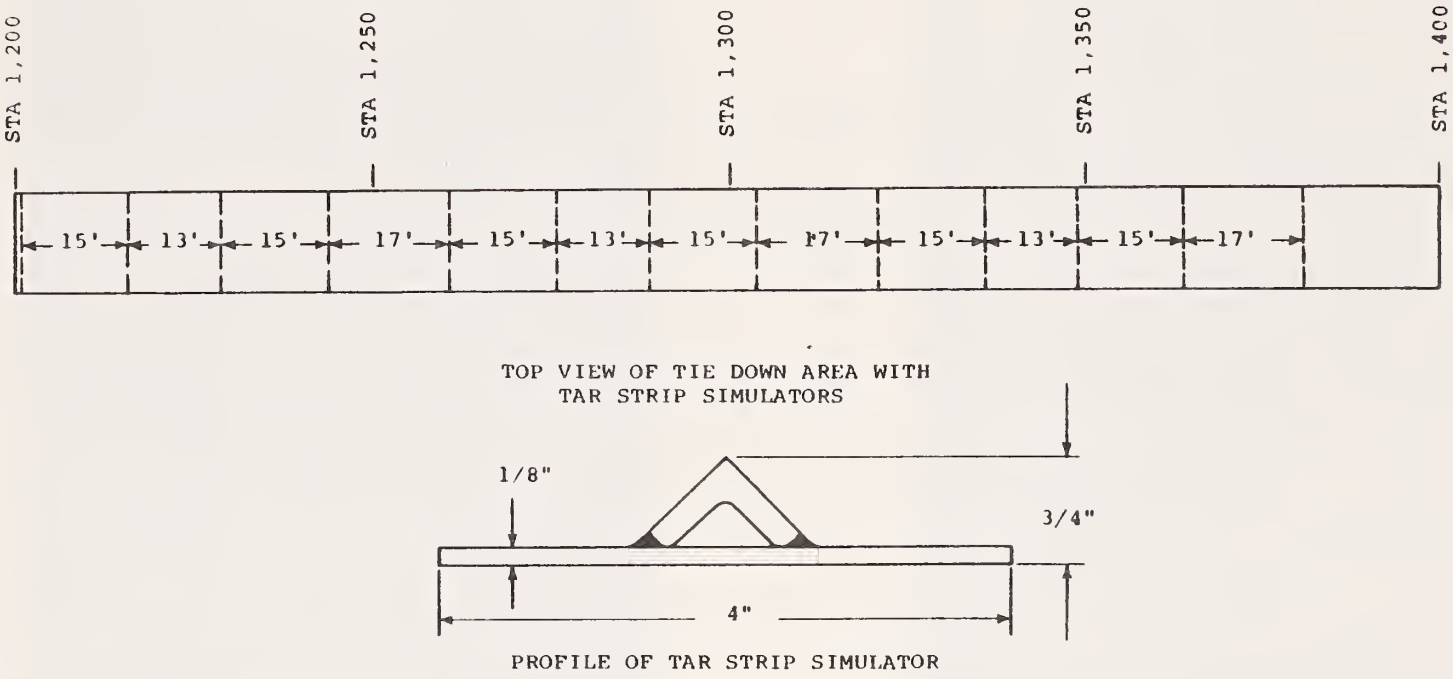


Figure A-2c. Ride Course Profile - Station Numbers 1,200 to 1,398 Inclusive.

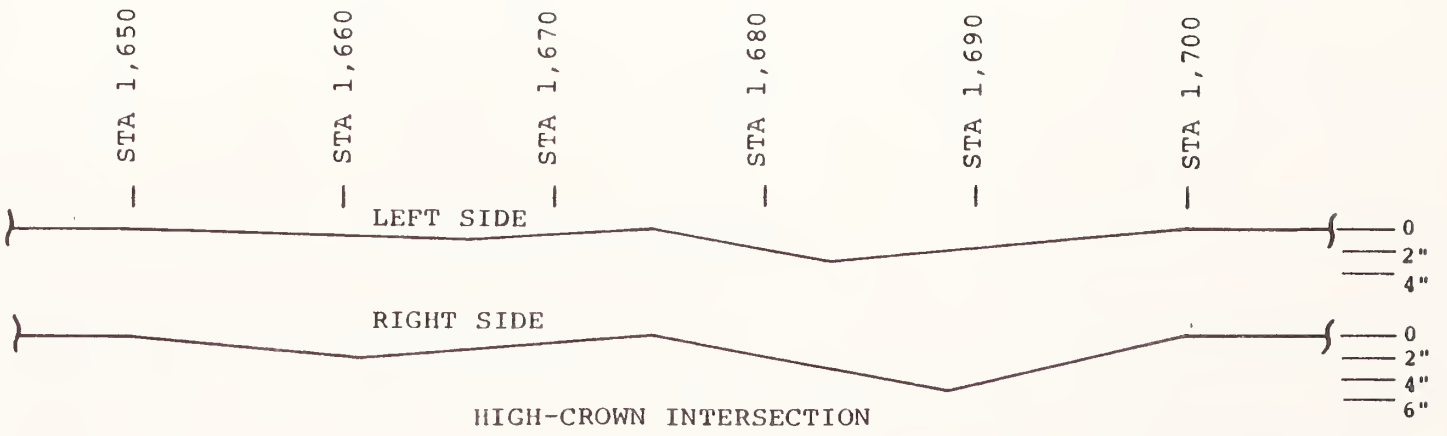


Figure A-2d. Ride Course Profile - Station Numbers 1,640 to 1,700 Inclusive.

COURSE STATION: 0-75 FEET

TWO INCHES DEEP

COURSE STATION: 175-250 FEET

THREE INCHES DEEP

Figure A-3. Random Chuckholes.

COURSE STATION: 350-425 FEET

Figure A-4. Sine Wave Generator.

COURSE STATION: 525 FEET

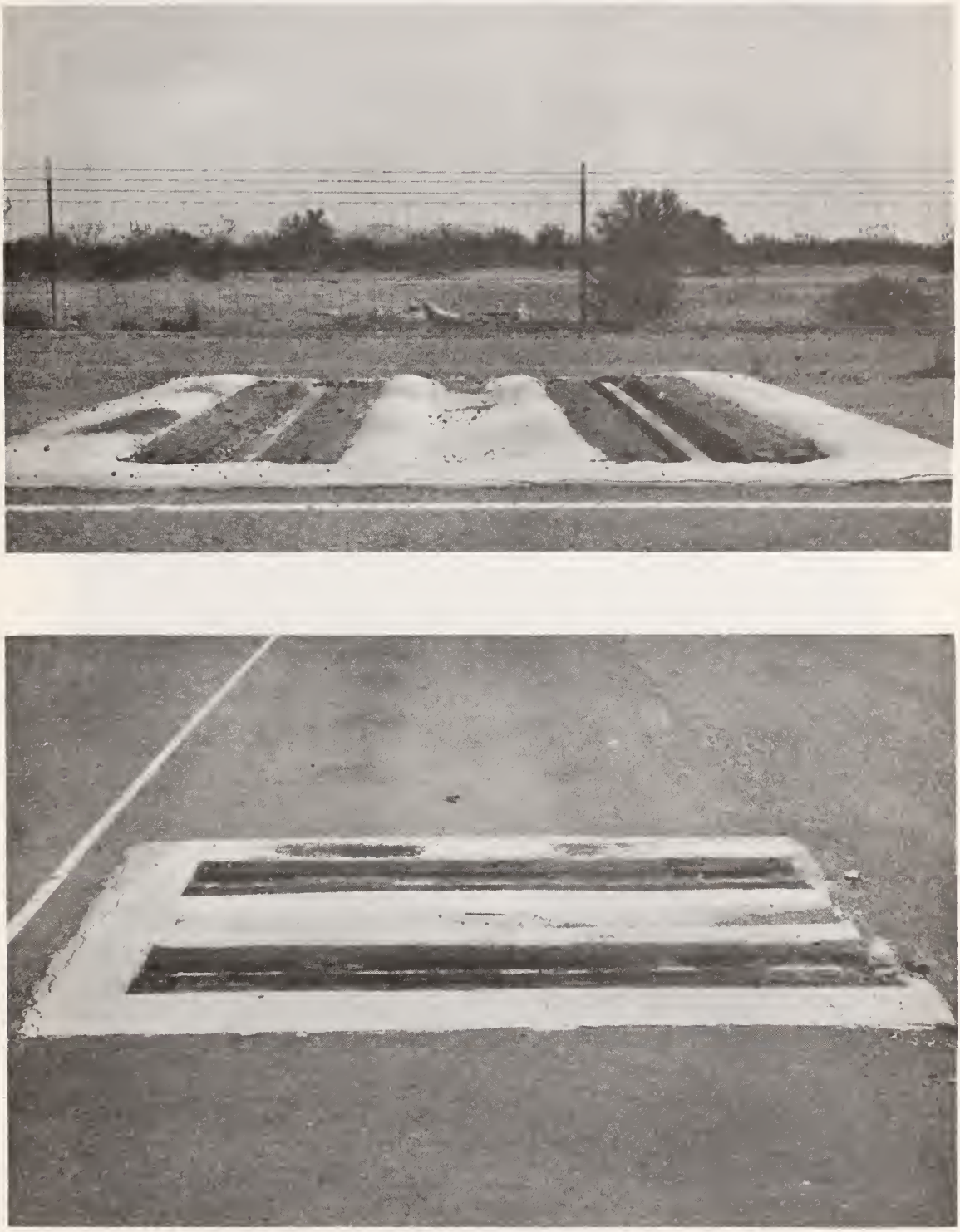
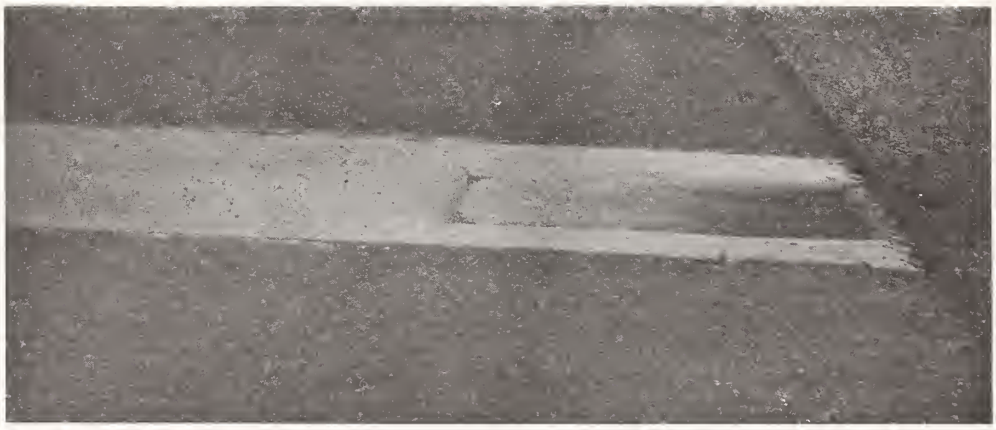


Figure A-5. Railroad Crossing.

COURSE STATION: 625 FEET



RIGHT SIDE ONLY

COURSE STATION: 725 FEET

OBLIQUE (27-DEGREE)

COURSE STATION: 825 FEET

PERPENDICULAR

Figure A-6. Two-inch Deep Dips.

COURSE STATION: 925-1,000 FEET

CHUCKHOLES

COURSE STATION: 1,200-1,400 FEET

IRREGULARITIES (TAP STRIP SIMULATORS)

Figure A-7. One-inch Deep Chuckholes and Pavement Irregularities Area.

COURSE STATION: 1,650-1,700 FEET

Figure A-8. High Crown Intersection.

APPENDIX B

NOVA OCCUPANT VERTICAL ACCELERATIONS VERSUS FREQUENCY

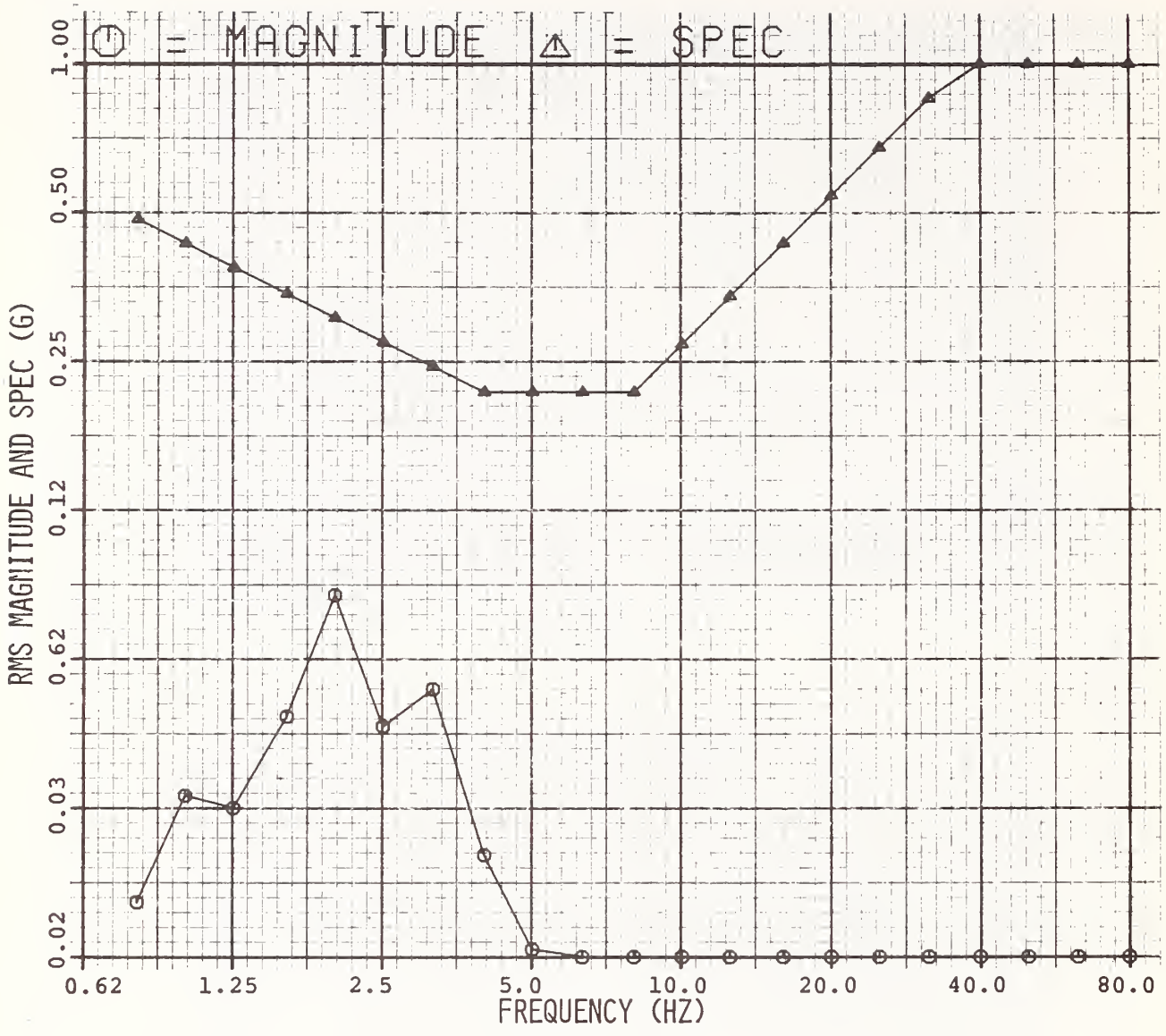


Figure B-1. Nova Driver Vertical Acceleration, Light Load, 5 mph.

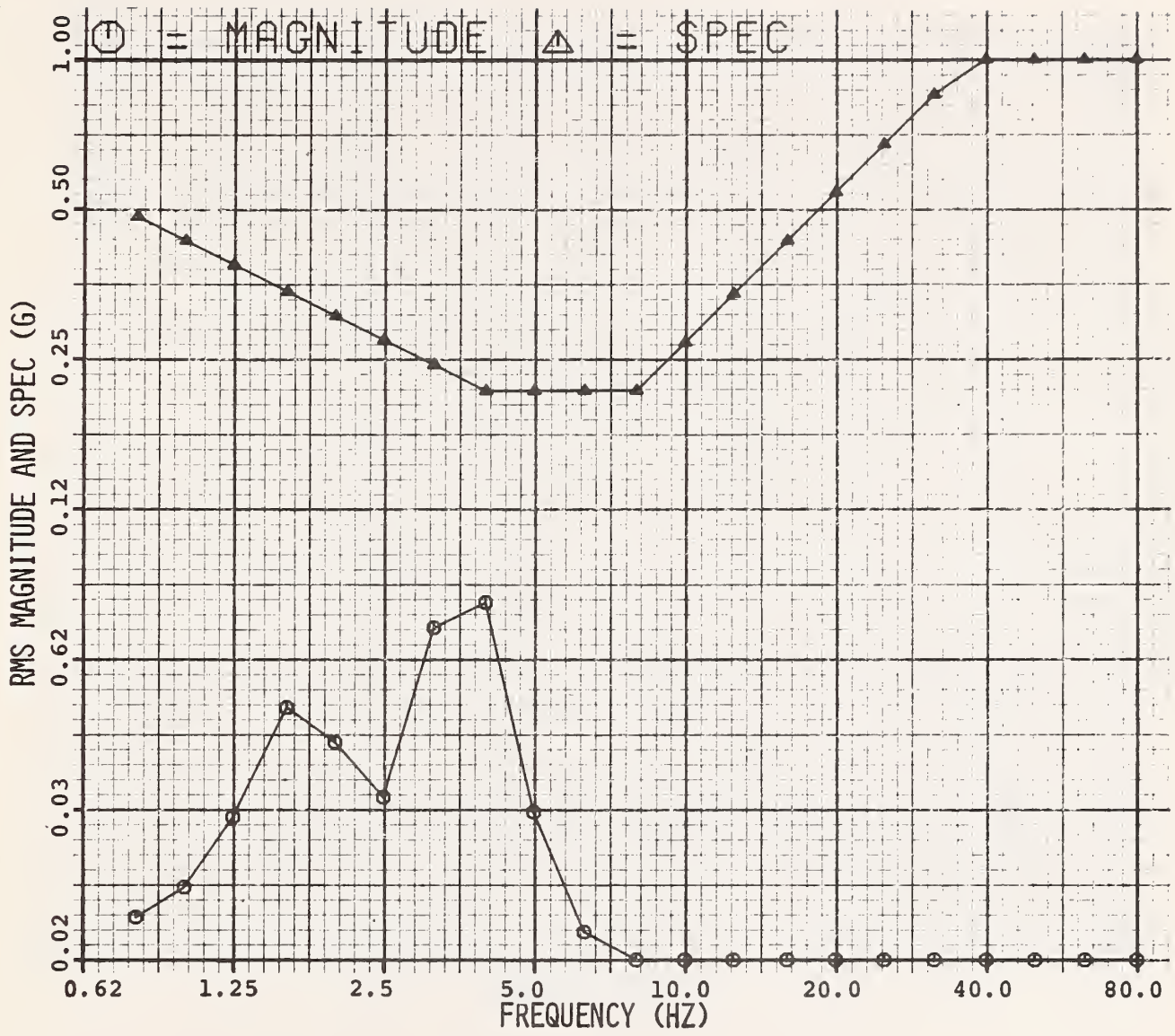


Figure B-2. Nova Driver Vertical Acceleration, Light Load, 10 mph.

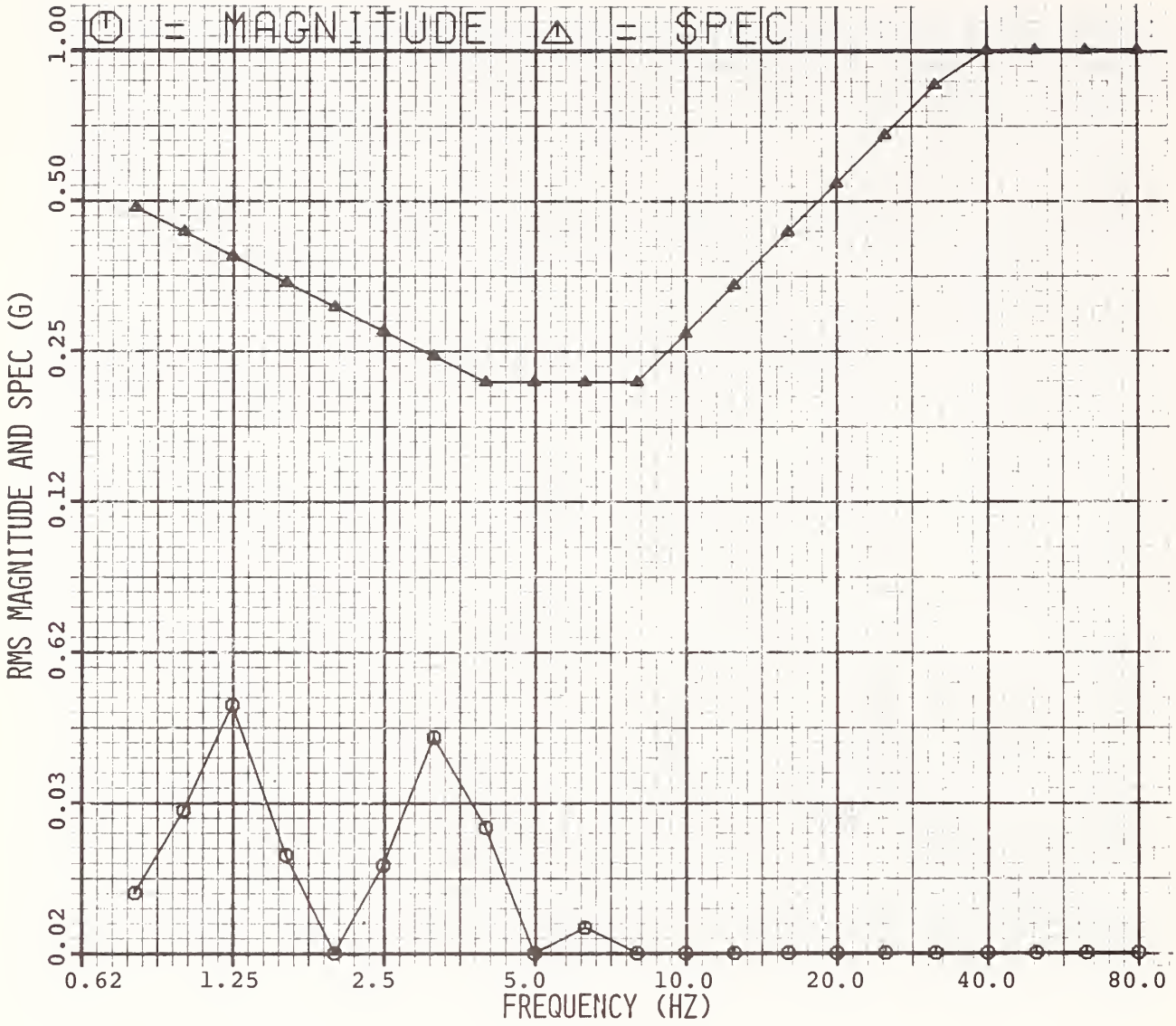


Figure B-3. Nova Driver Vertical Acceleration, Light Load, 20 mph.

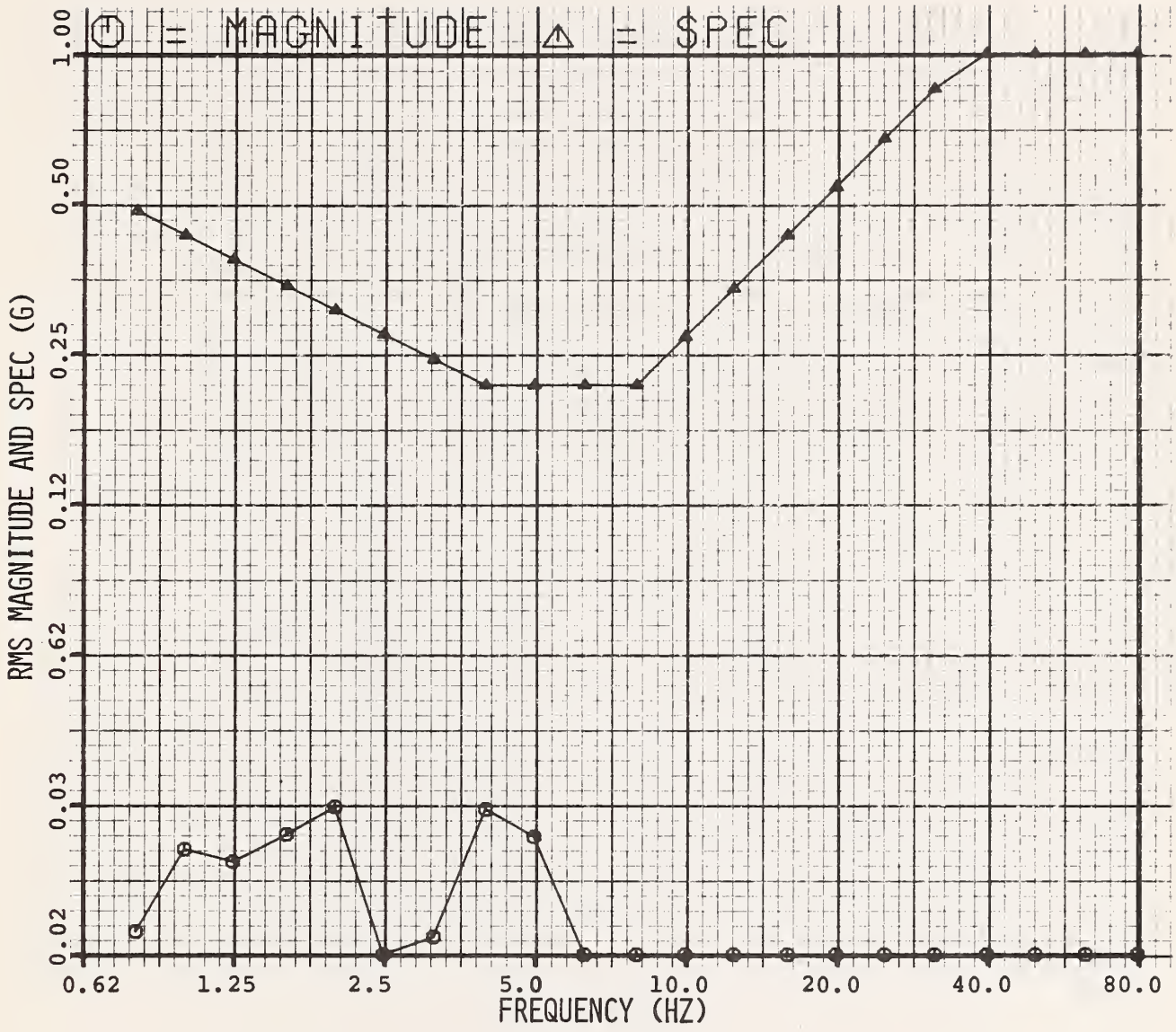


Figure B-4. Nova Driver Vertical Acceleration, Light Load, 30 mph.

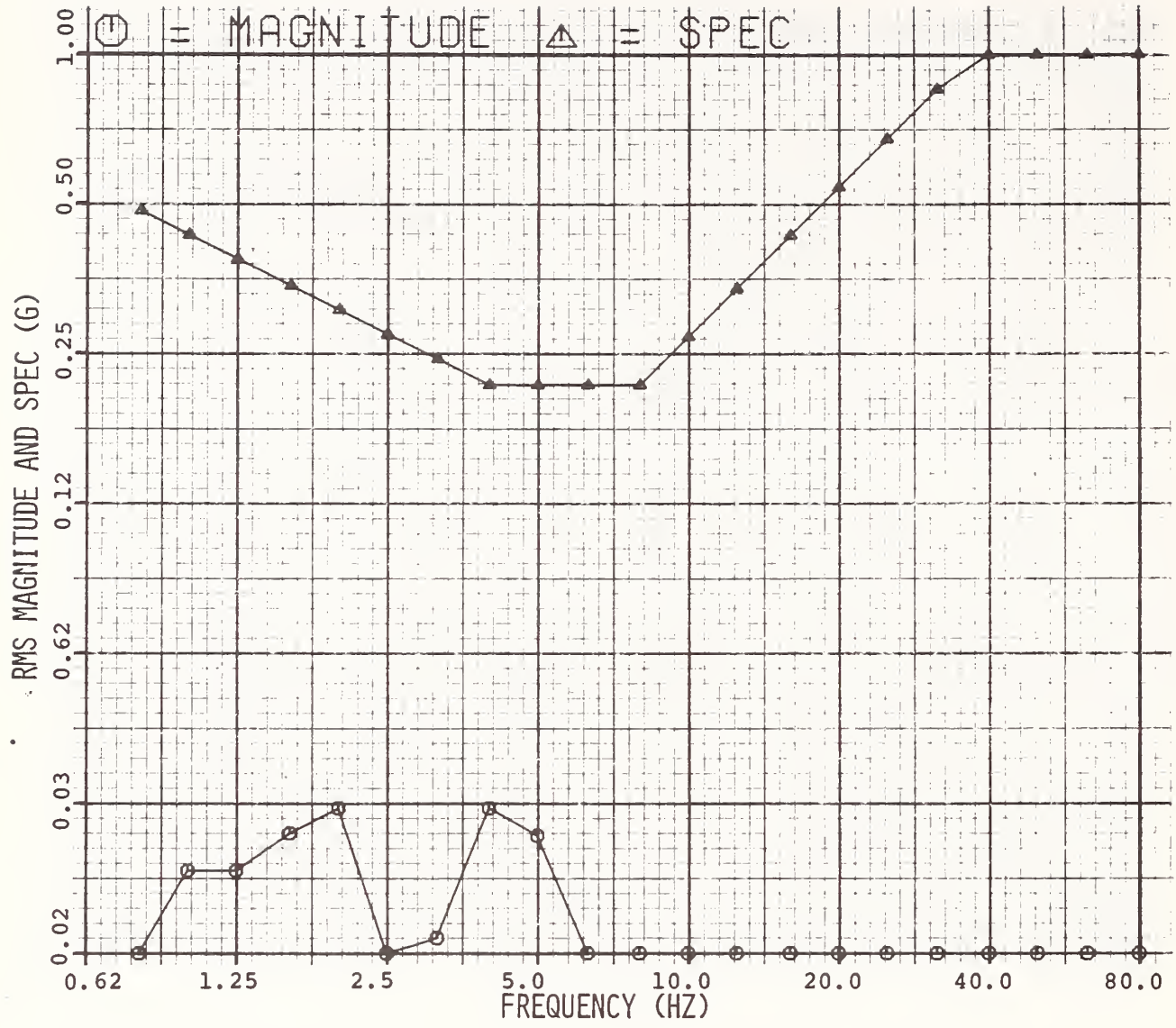


Figure B-5. Nova Driver Vertical Acceleration, Light Load, 40 mph.

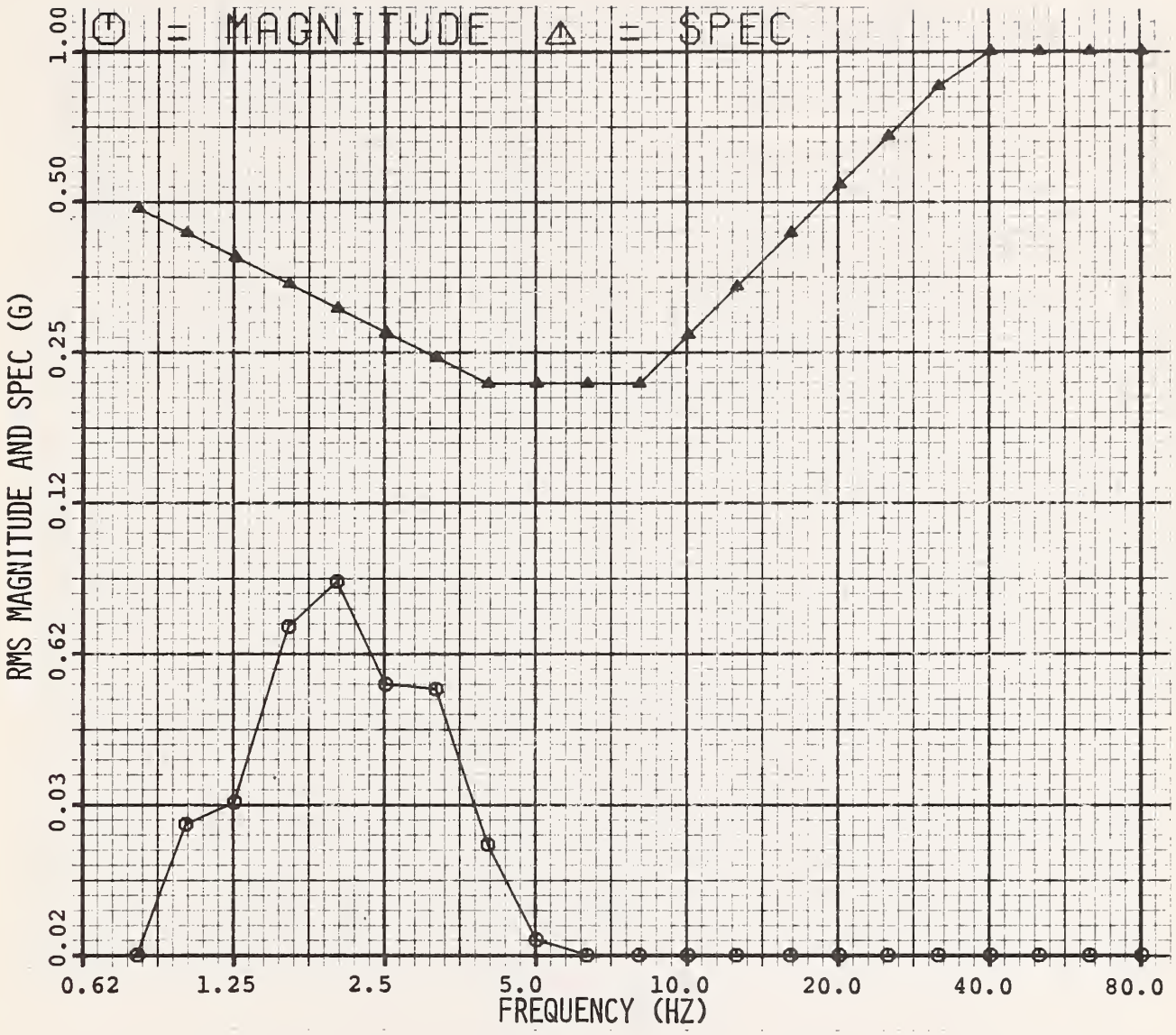


Figure B-6. Nova Driver Vertical Acceleration, Heavy Load, 5 mph.

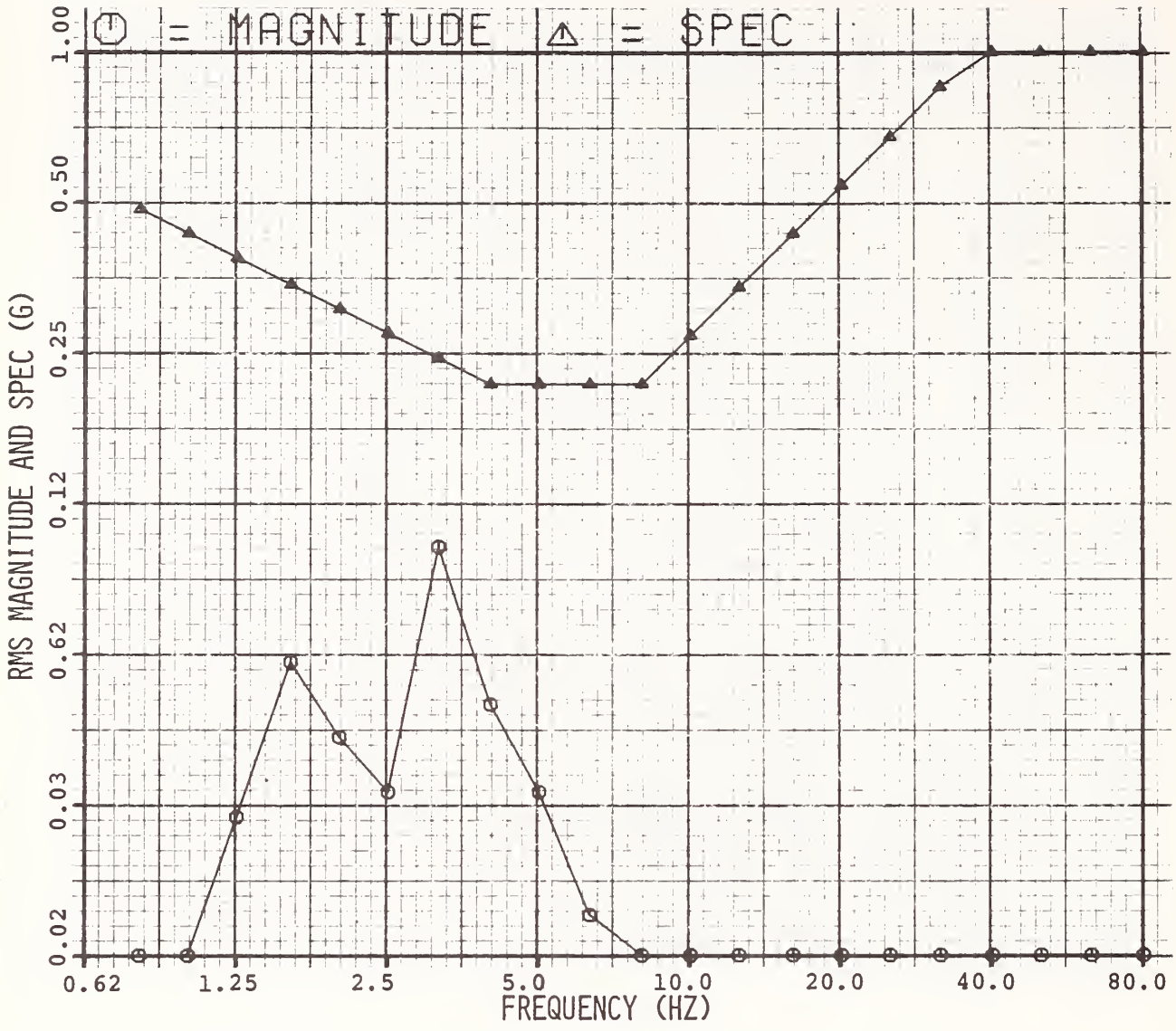


Figure B-7. Nova Driver Vertical Acceleration, Heavy Load, 10 mph.

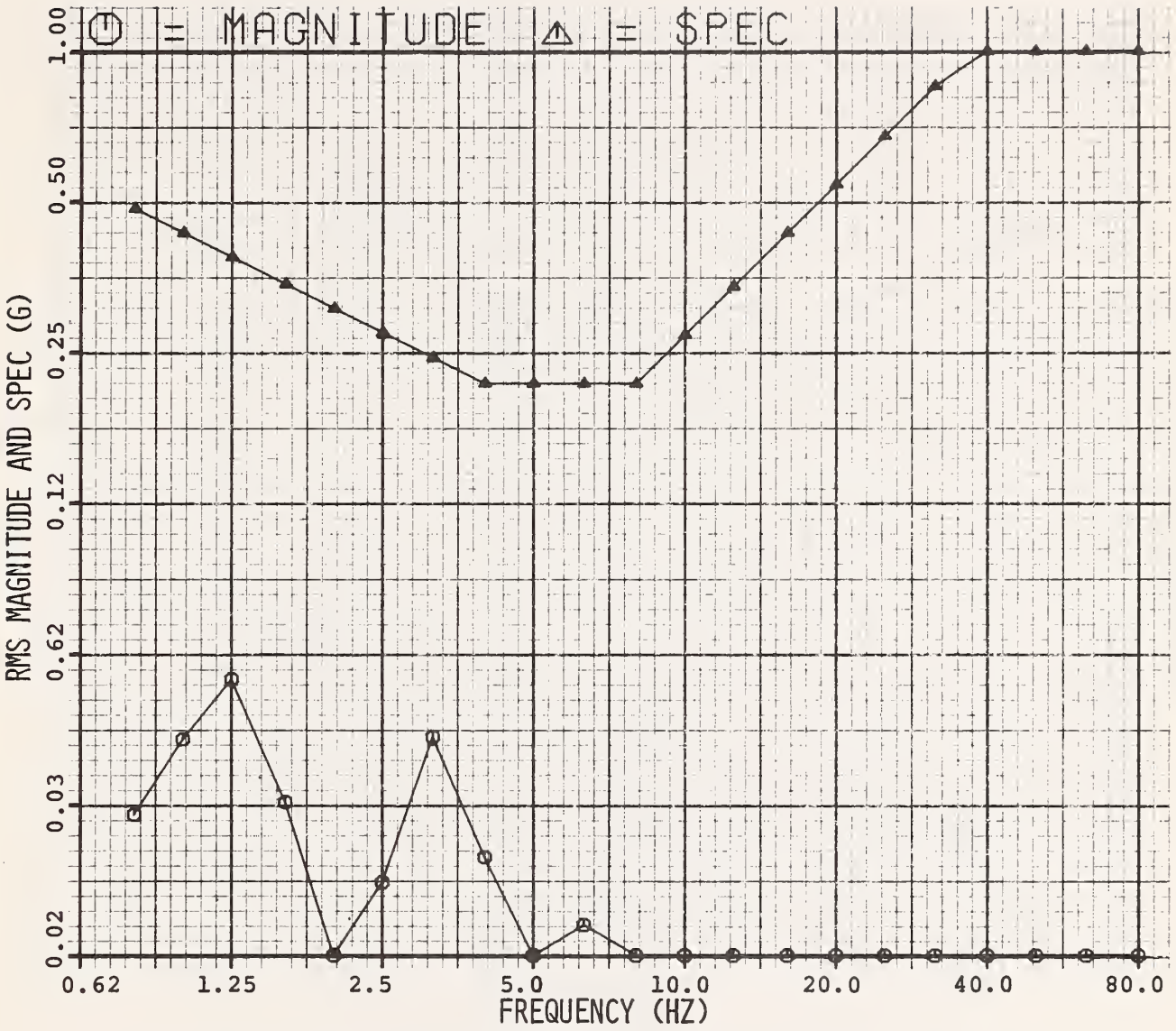


Figure B-8. Nova Driver Vertical Acceleration, Heavy Load, 20 mph.

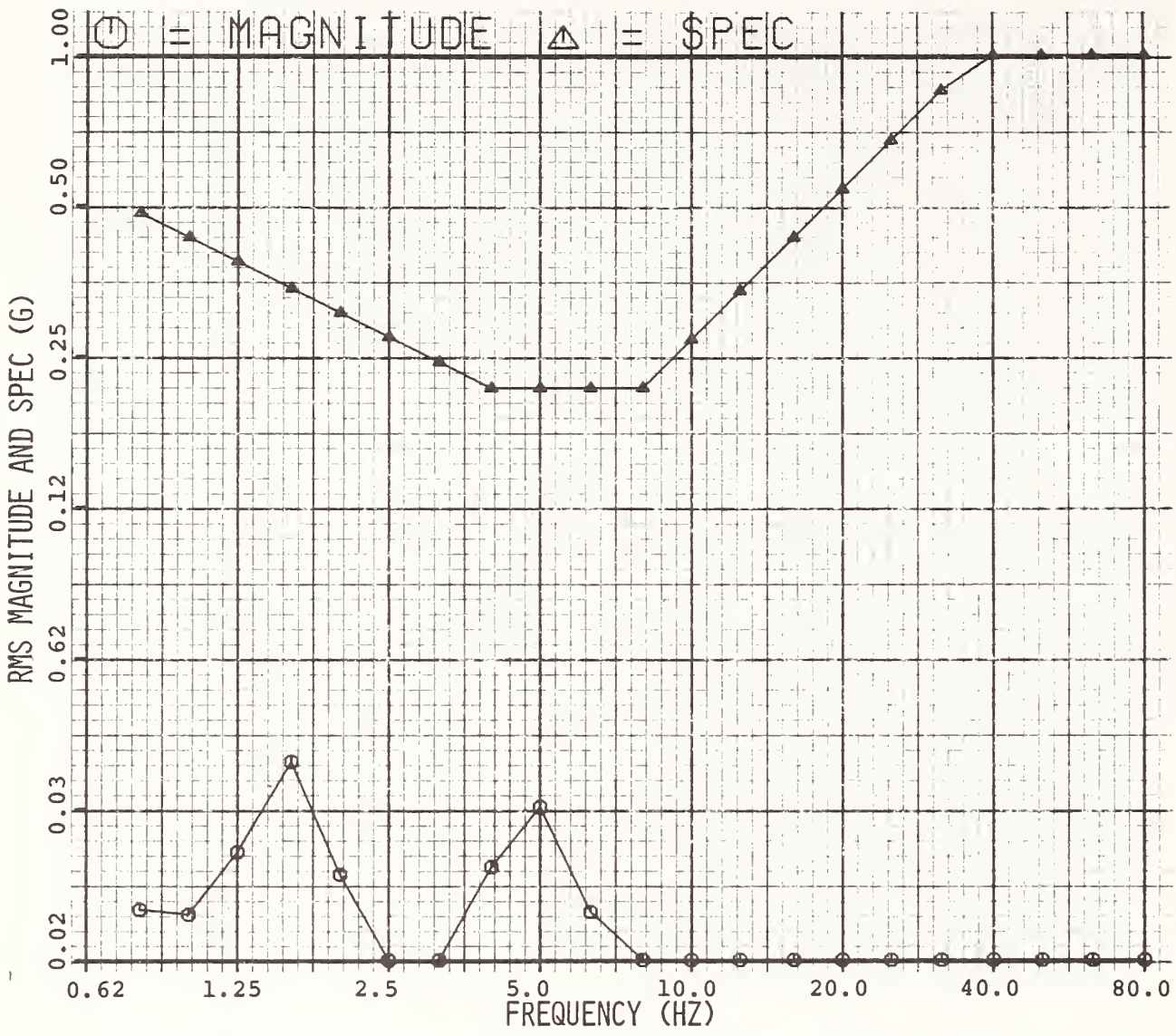


Figure B-9. Nova Driver Vertical Acceleration, Heavy Load, 30 mph.

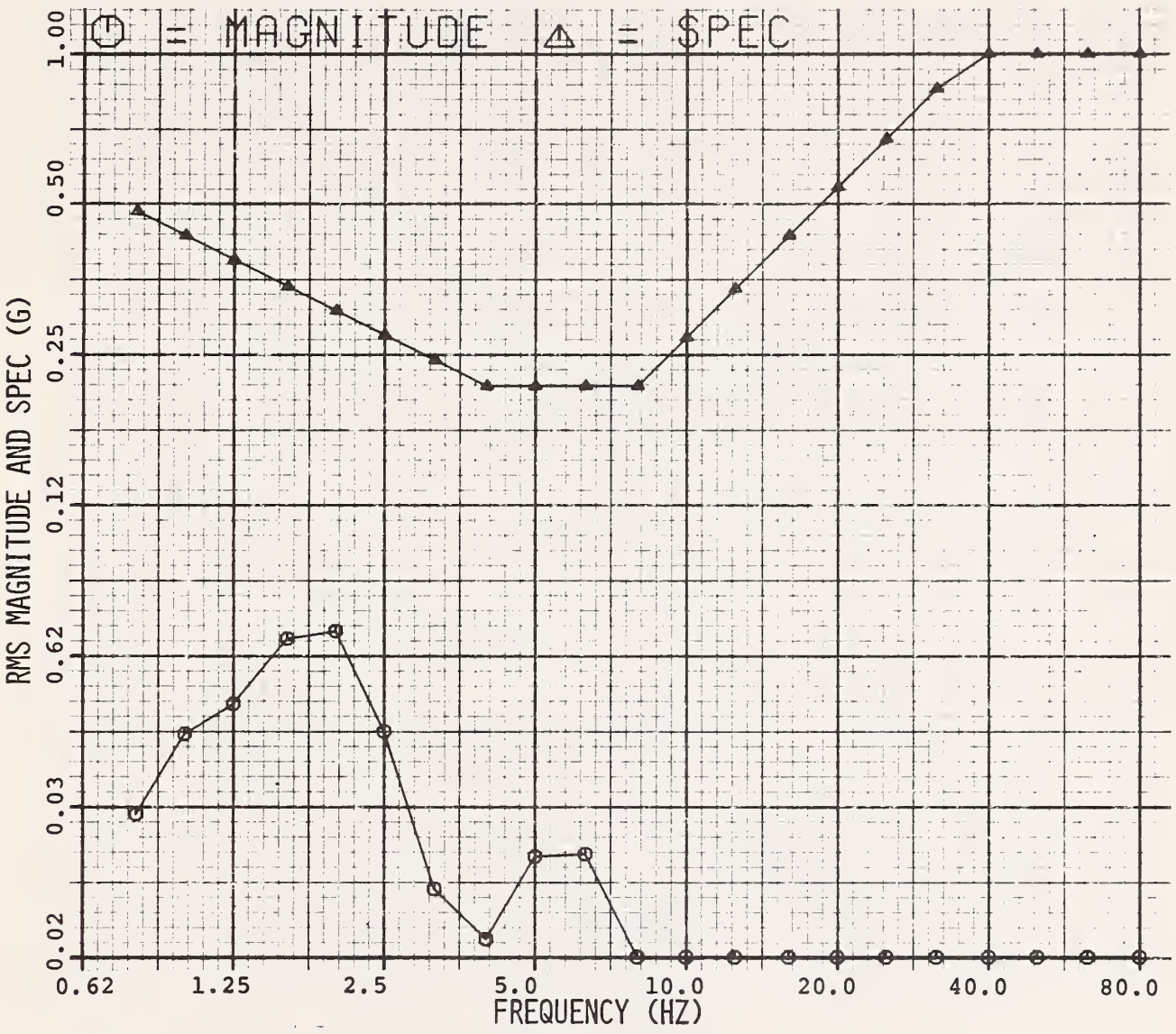


Figure B-10. Nova Driver Vertical Acceleration, Heavy Load, 40 mph.

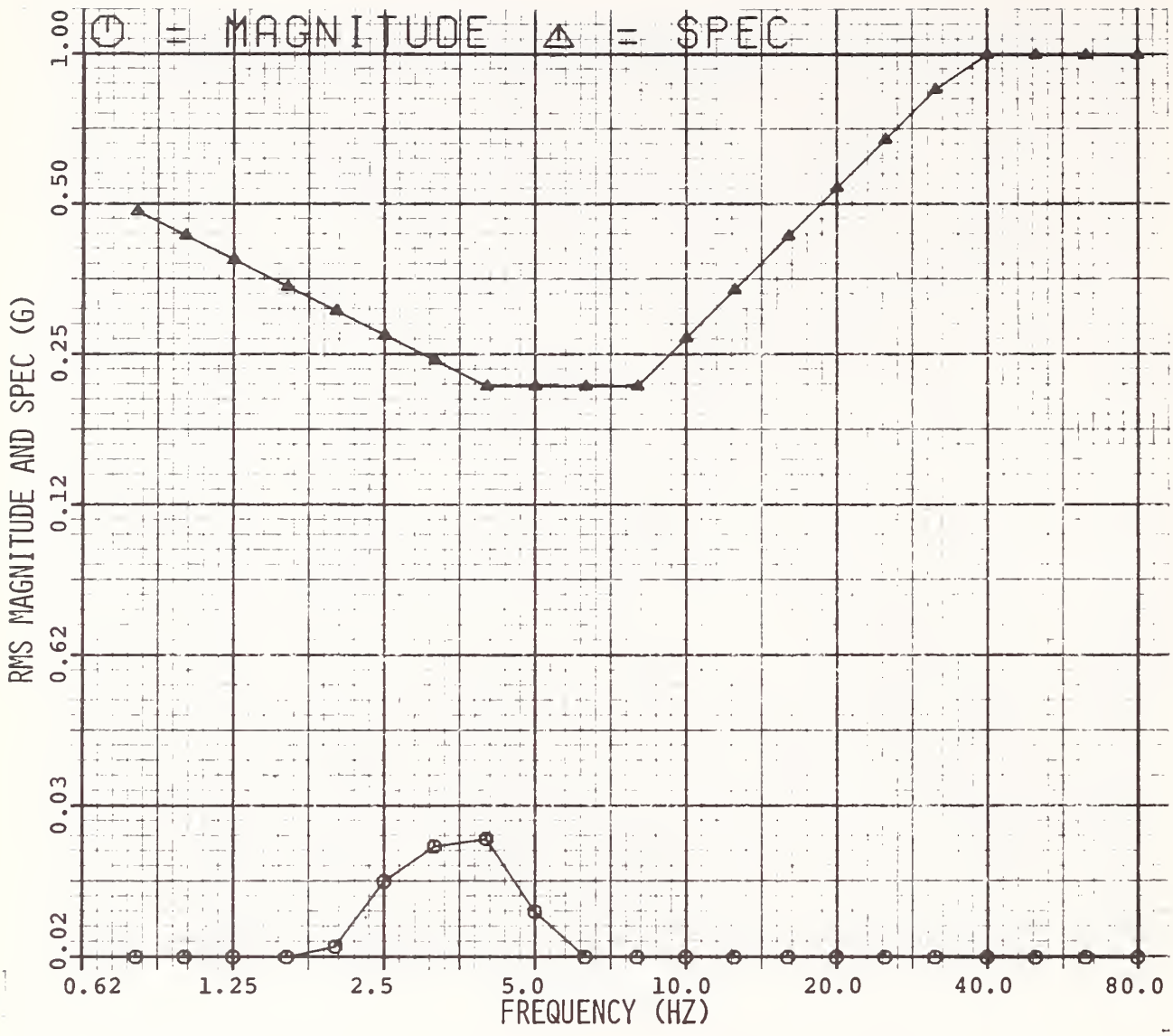


Figure B-11. Nova Driver Vertical Acceleration, Urban Driving Course.

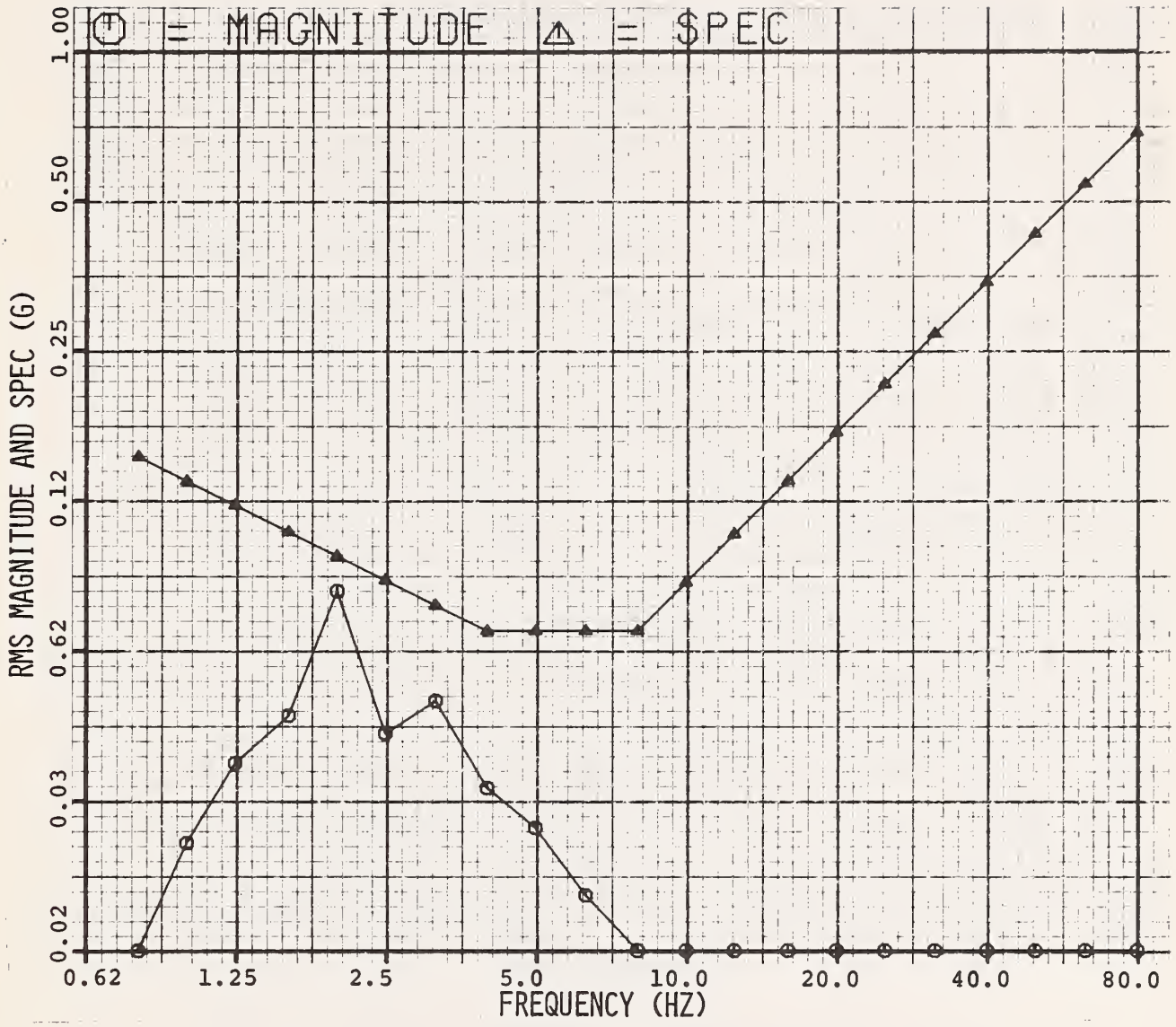


Figure B-12. Nova Passenger Vertical Acceleration, Light Load, 5 mph.

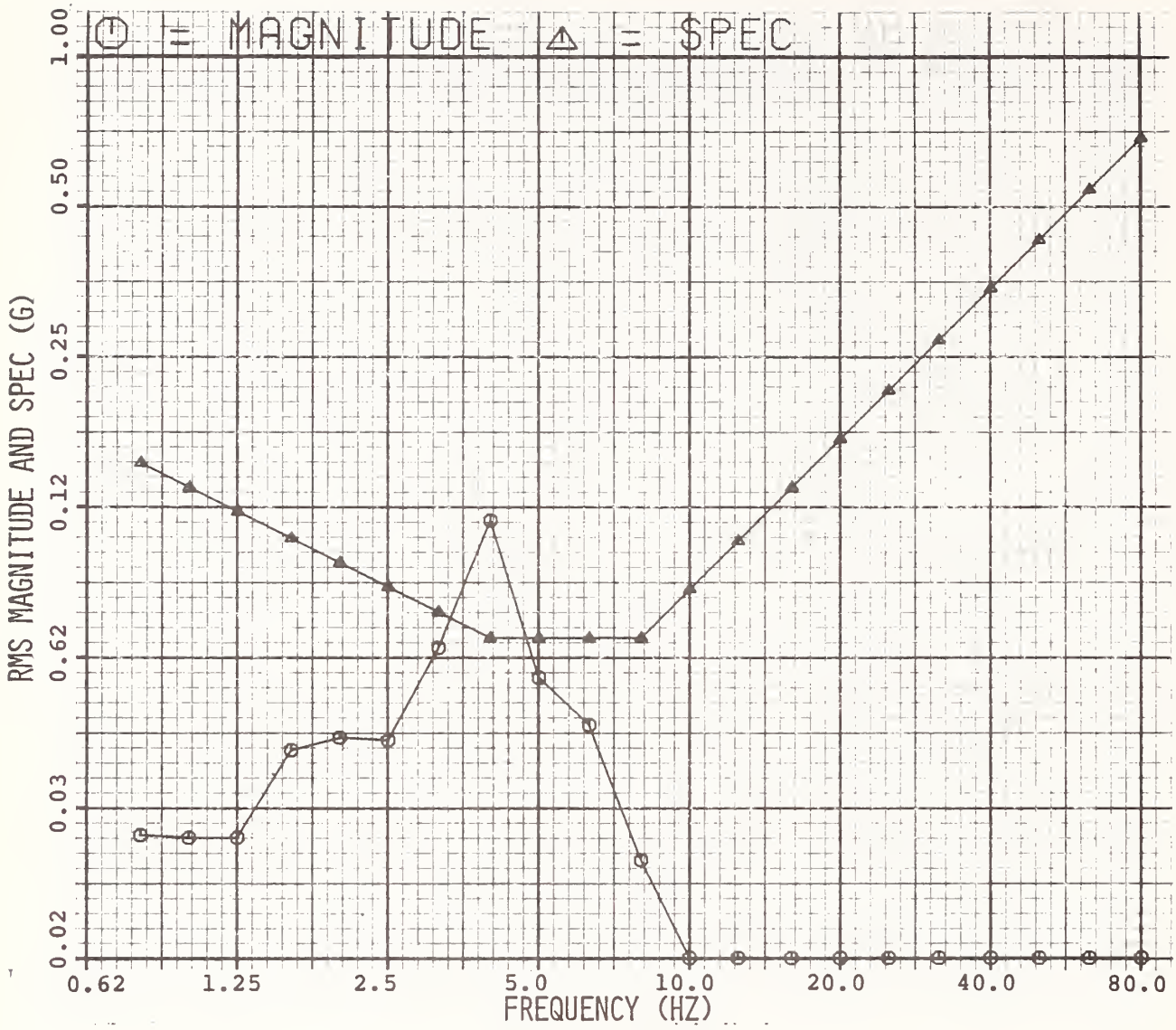


Figure B-13. Nova Passenger Vertical Acceleration, Light Load, 10 mph.

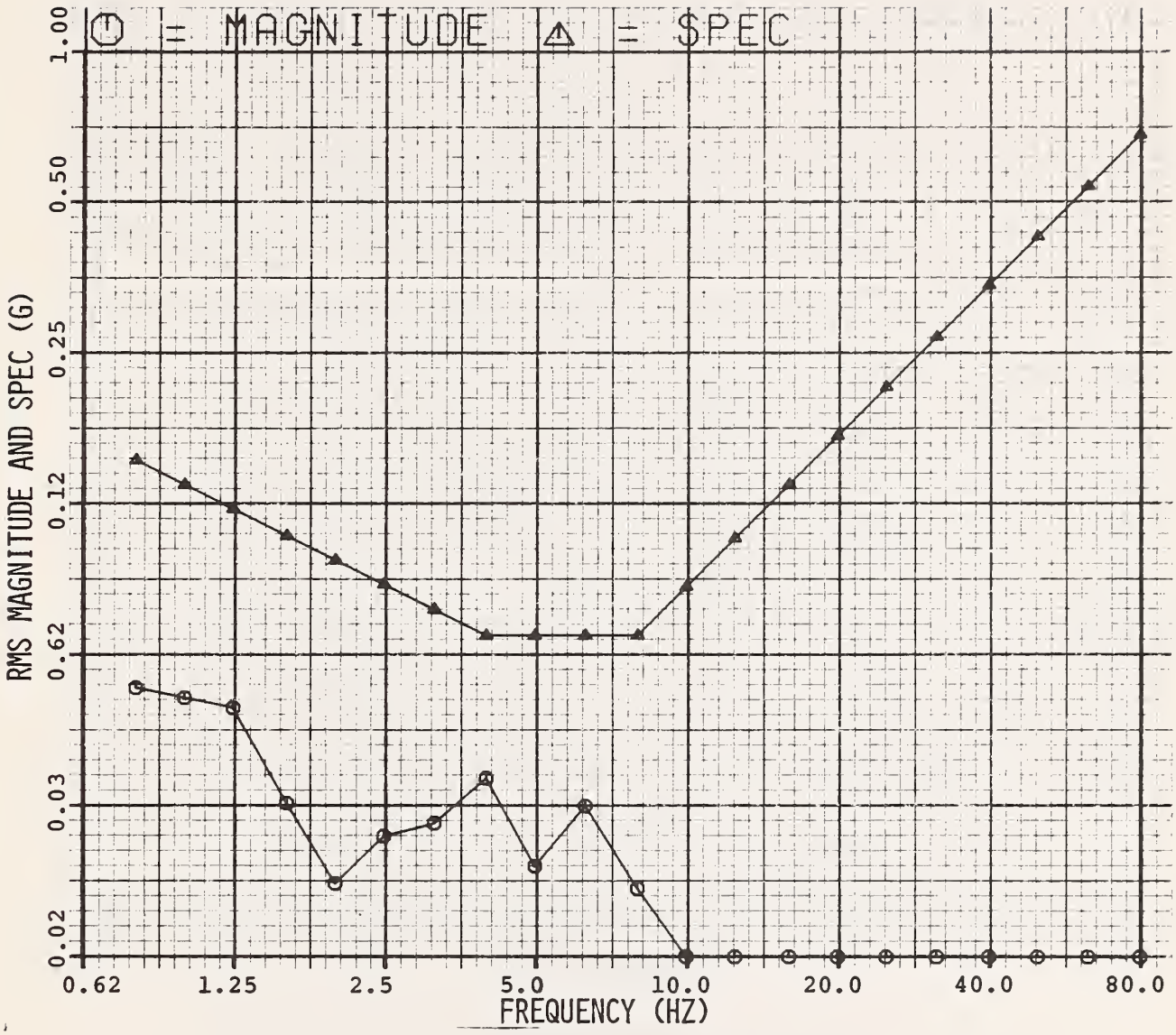


Figure B-14. Nova Passenger Vertical Acceleration, Light Load, 20 mph.

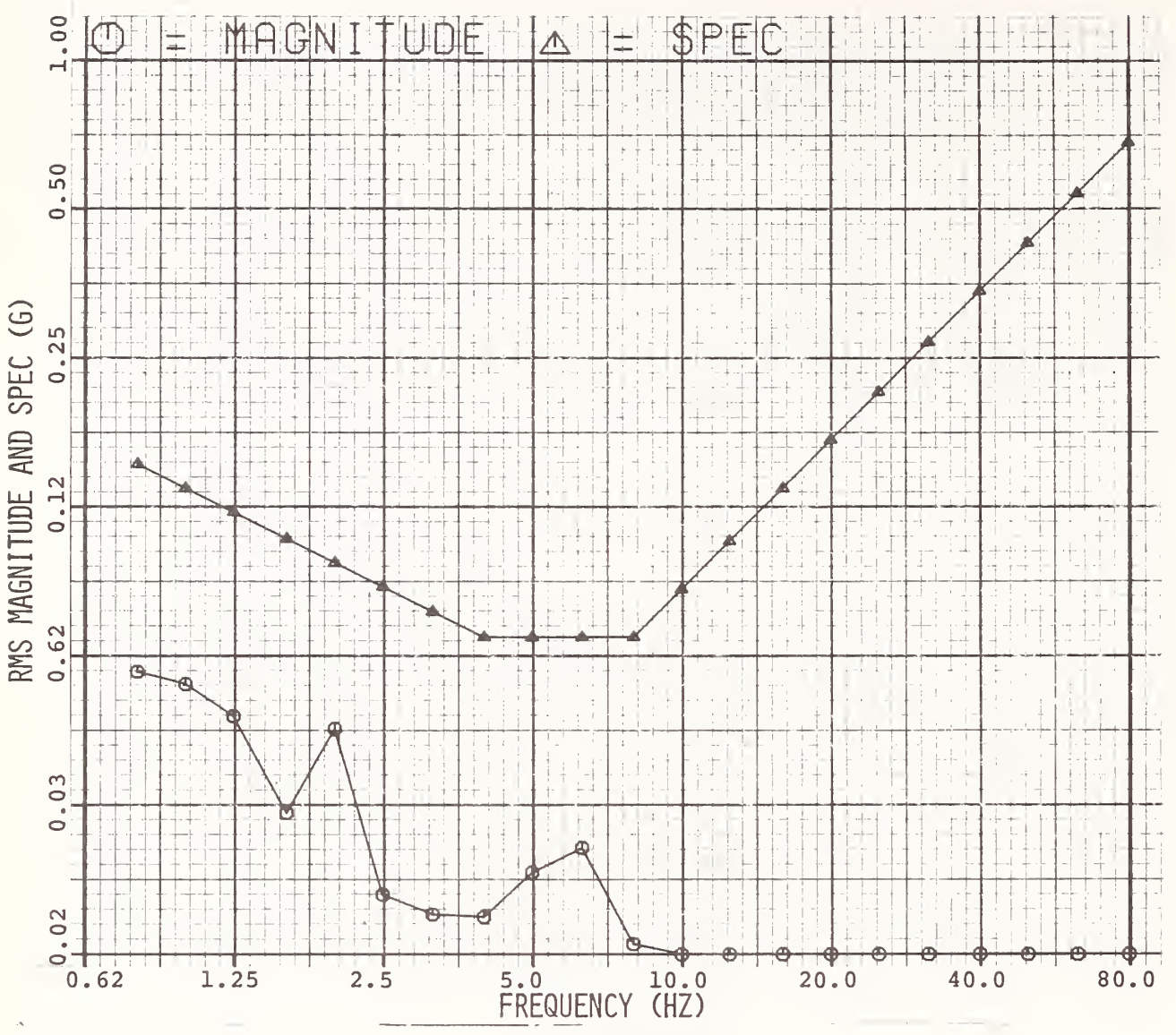


Figure B-15. Nova Passenger Vertical Acceleration, Light Load, 30 mph.

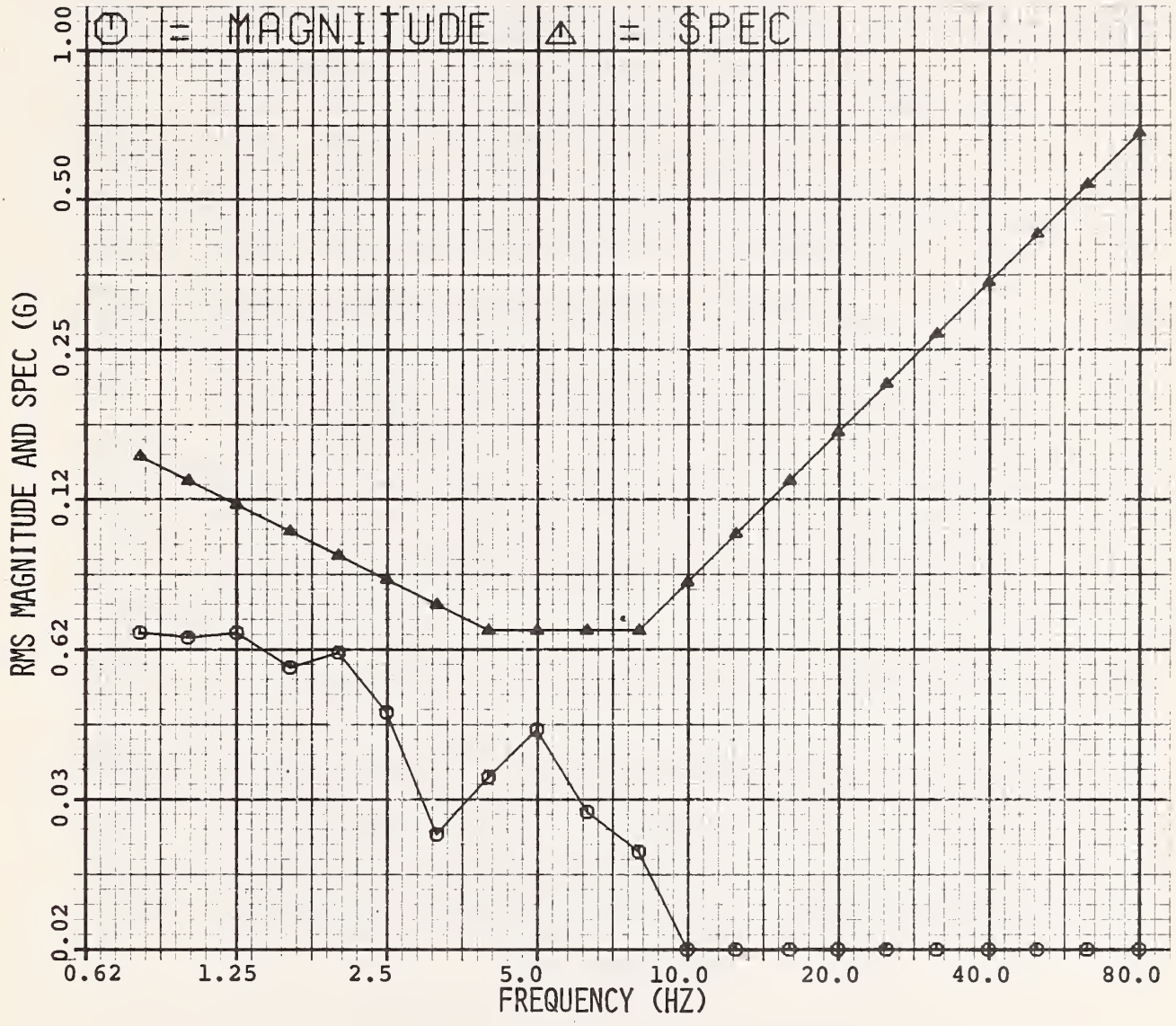


Figure B-16. Nova Passenger Vertical Acceleration, Light Load, 40 mph.

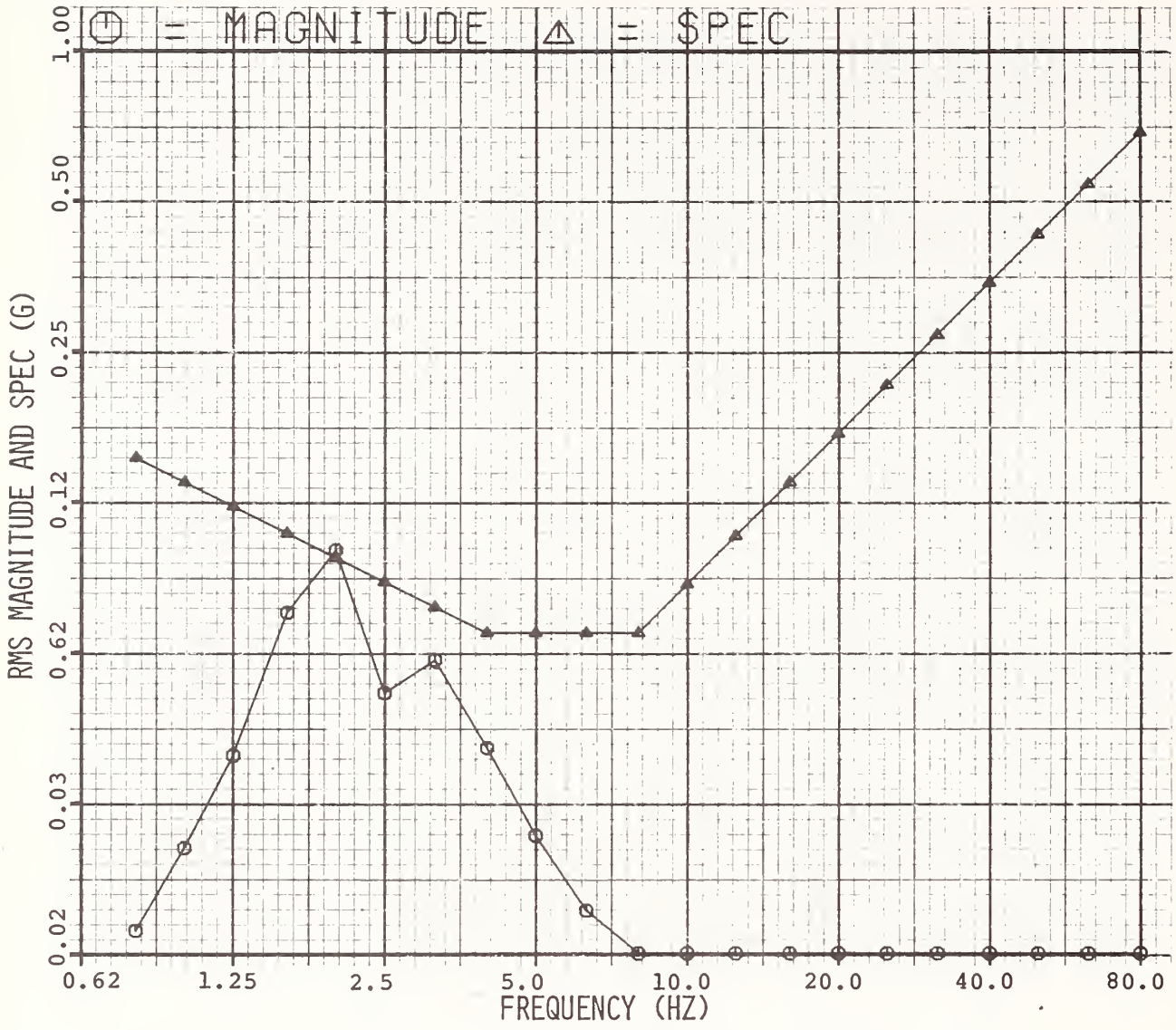


Figure B-17. Nova Passenger Vertical Acceleration, Heavy Load, 5 mph.

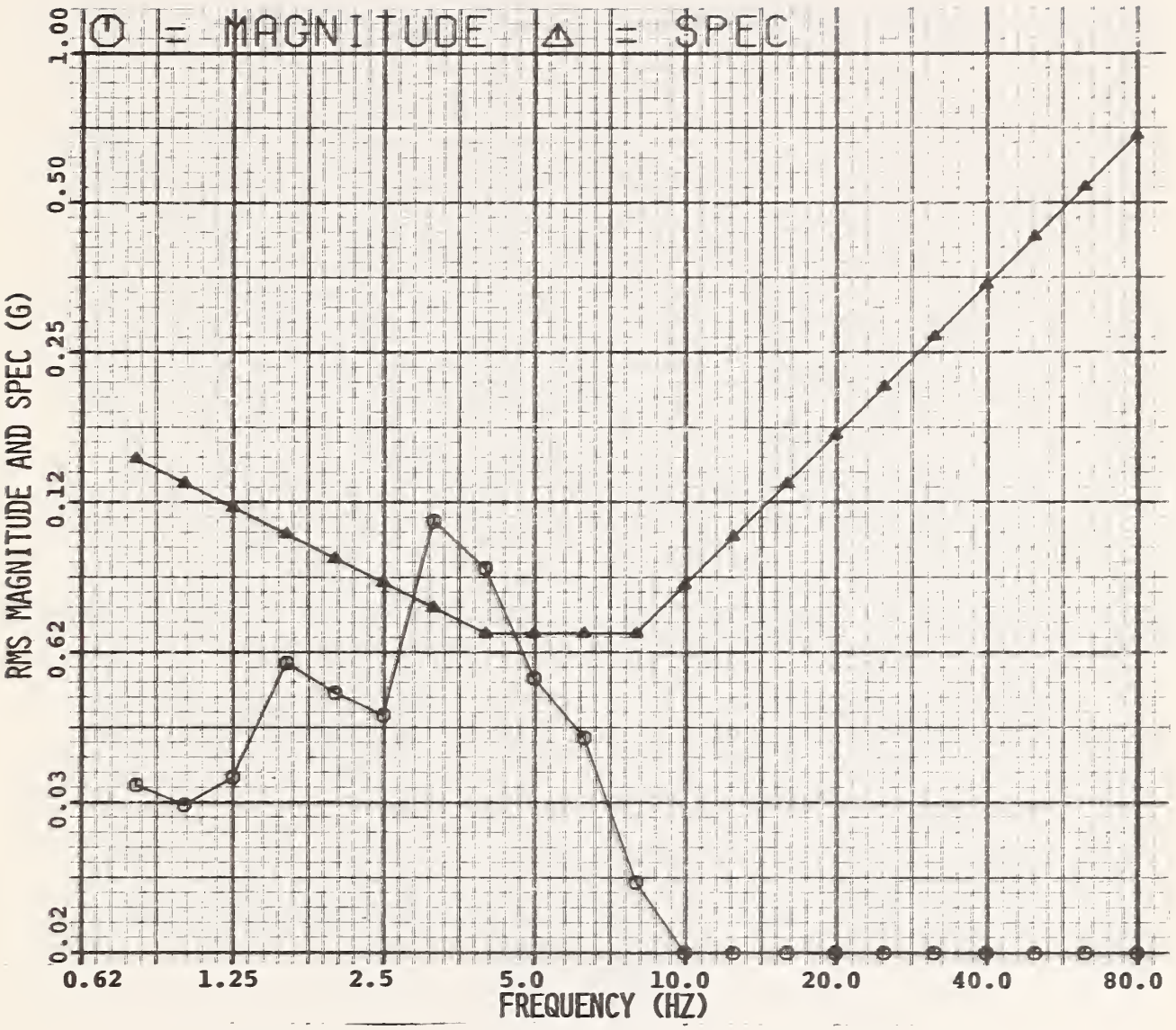


Figure B-18. Nova Passenger Vertical Acceleration, Heavy Load, 10 mph.

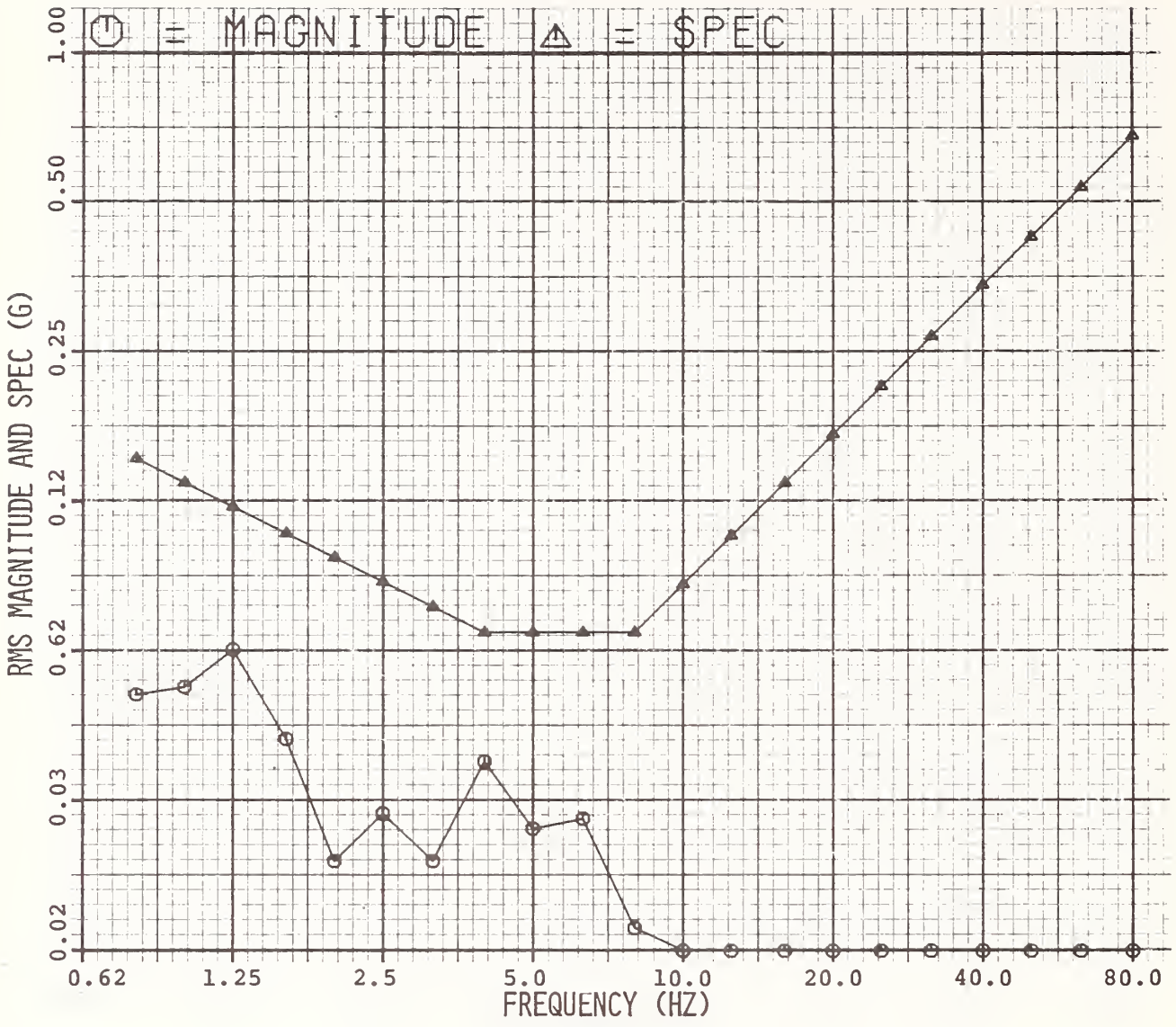


Figure B-19. Nova Passenger Vertical Acceleration, Heavy Load, 20 mph.

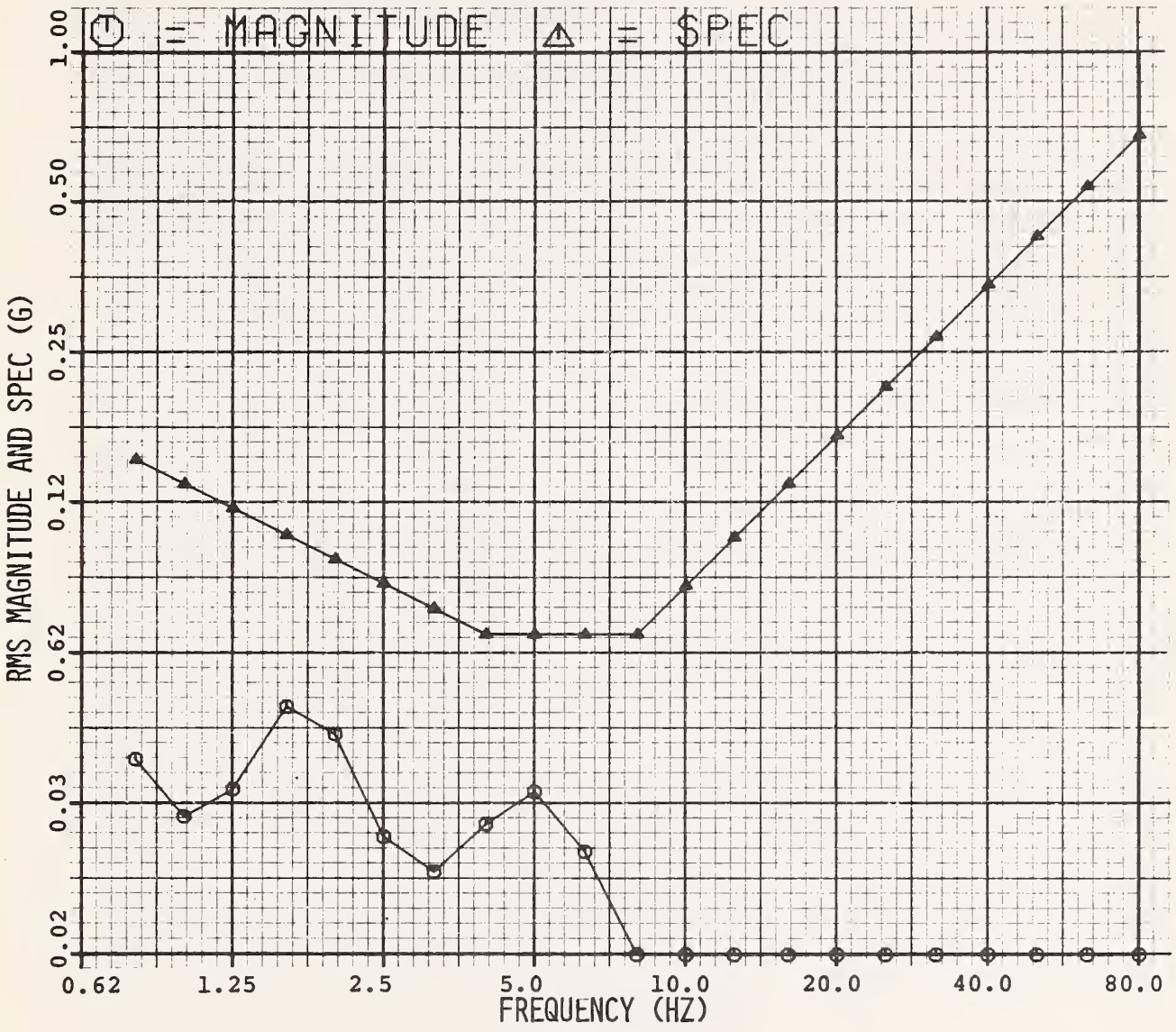


Figure B-20. Nova Passenger Vertical Acceleration, Heavy Load, 30 mph.

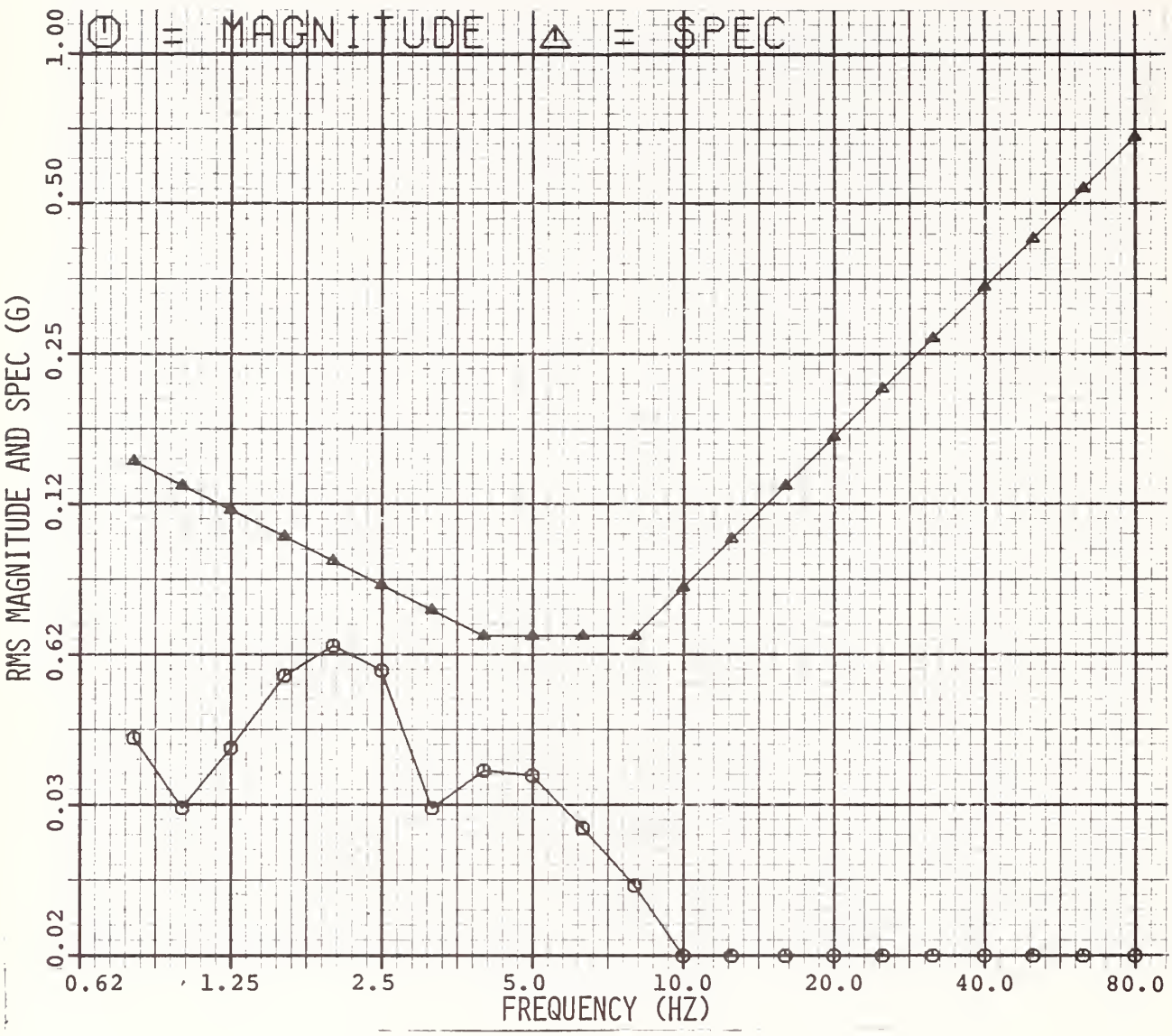


Figure B-21. Nova Passenger Vertical Vibration, Heavy Load, 40 mph.

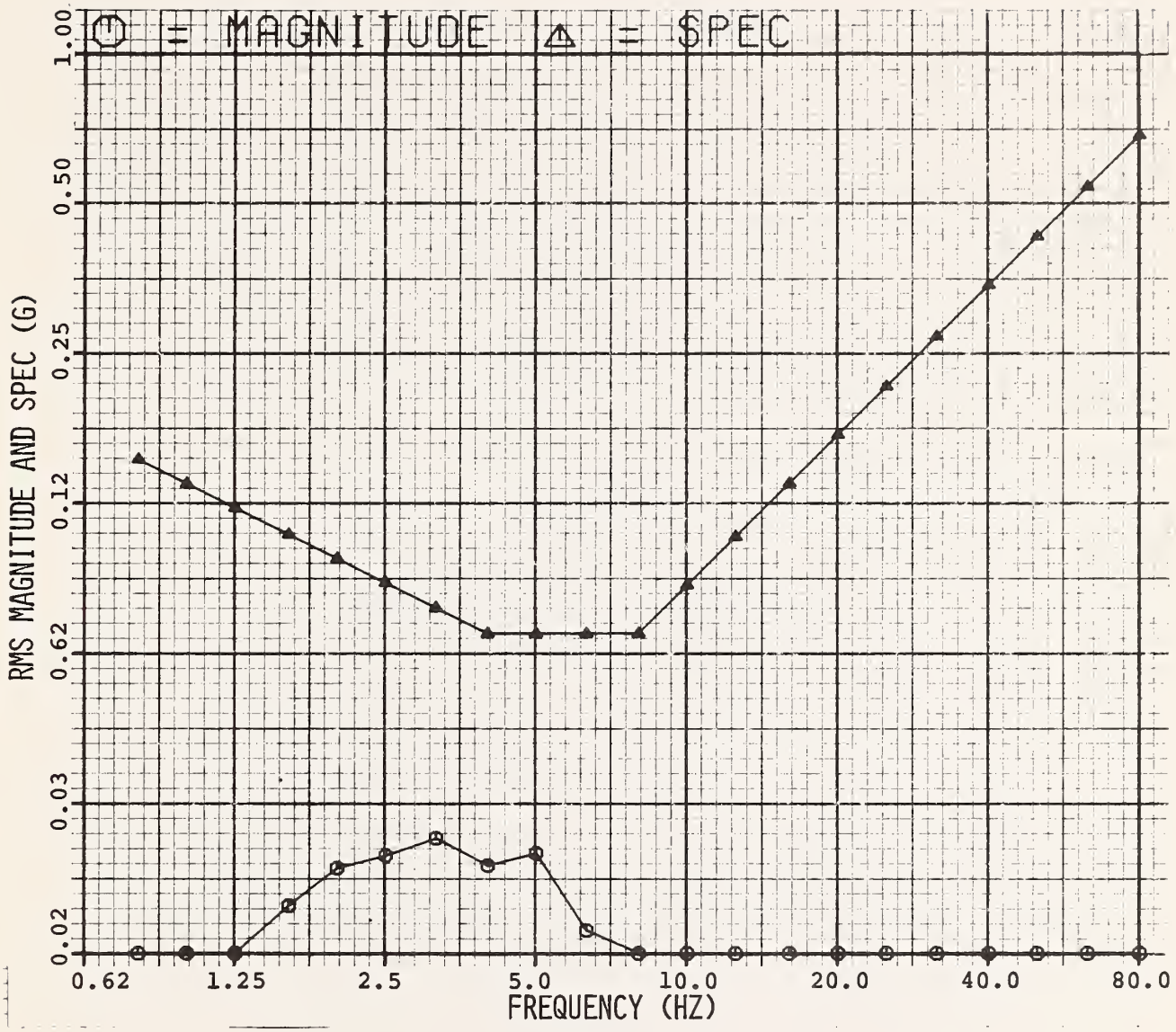


Figure B-22. Nova Passenger Vertical Acceleration, Urban Driving Course.

APPENDIX C

ASL OCCUPANT VERTICAL ACCELERATIONS VERSUS FREQUENCY

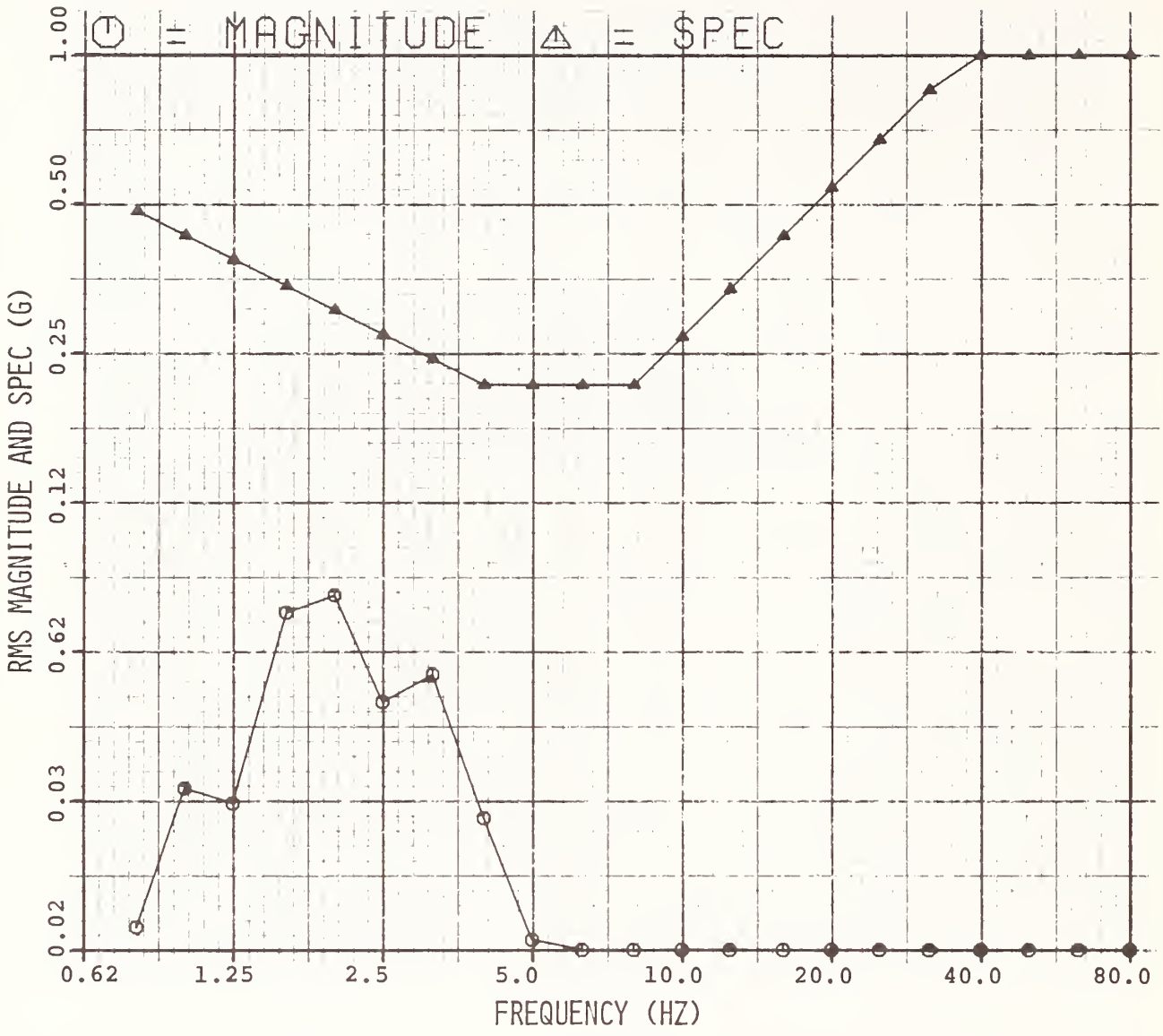


Figure C-1. ASL Driver Vertical Acceleration, Light Load (Wheelchair Passenger), 5 mph.

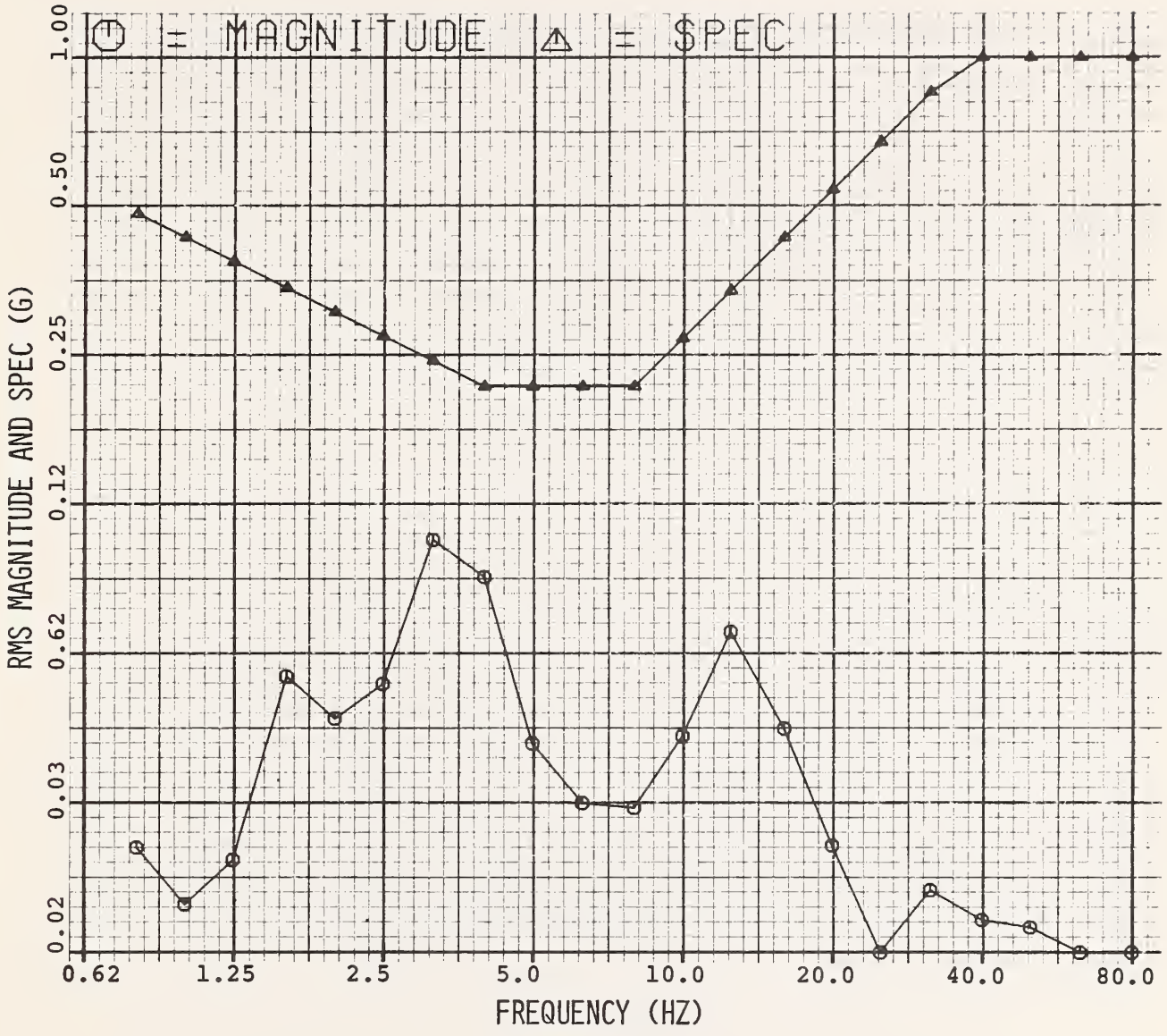


Figure C-2. ASL Driver Vertical Acceleration, Light Load (Wheelchair Passenger), 10 mph.

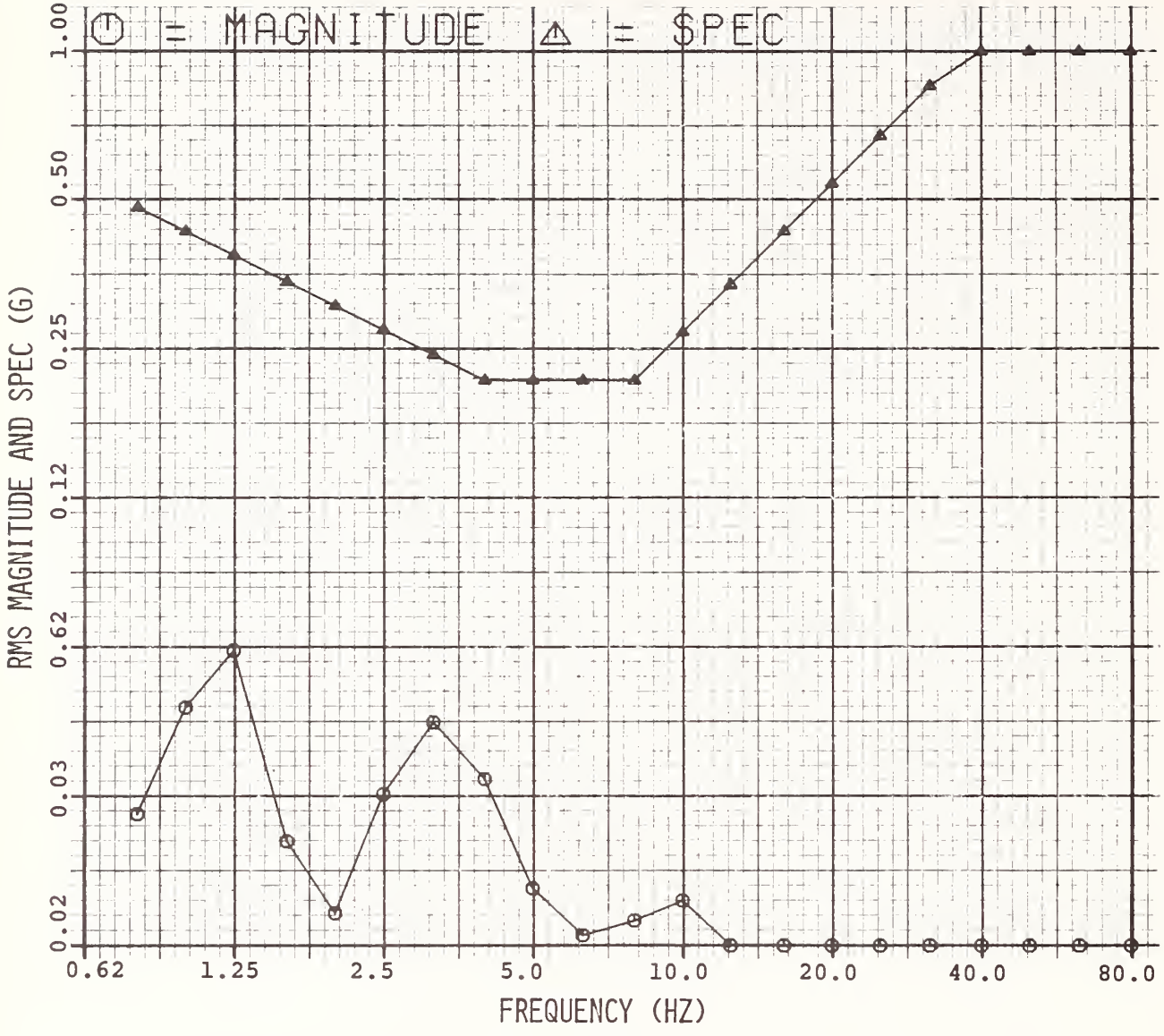


Figure C-3. ASL Driver Vertical Acceleration, Light Load (Wheelchair Passenger), 20 mph.

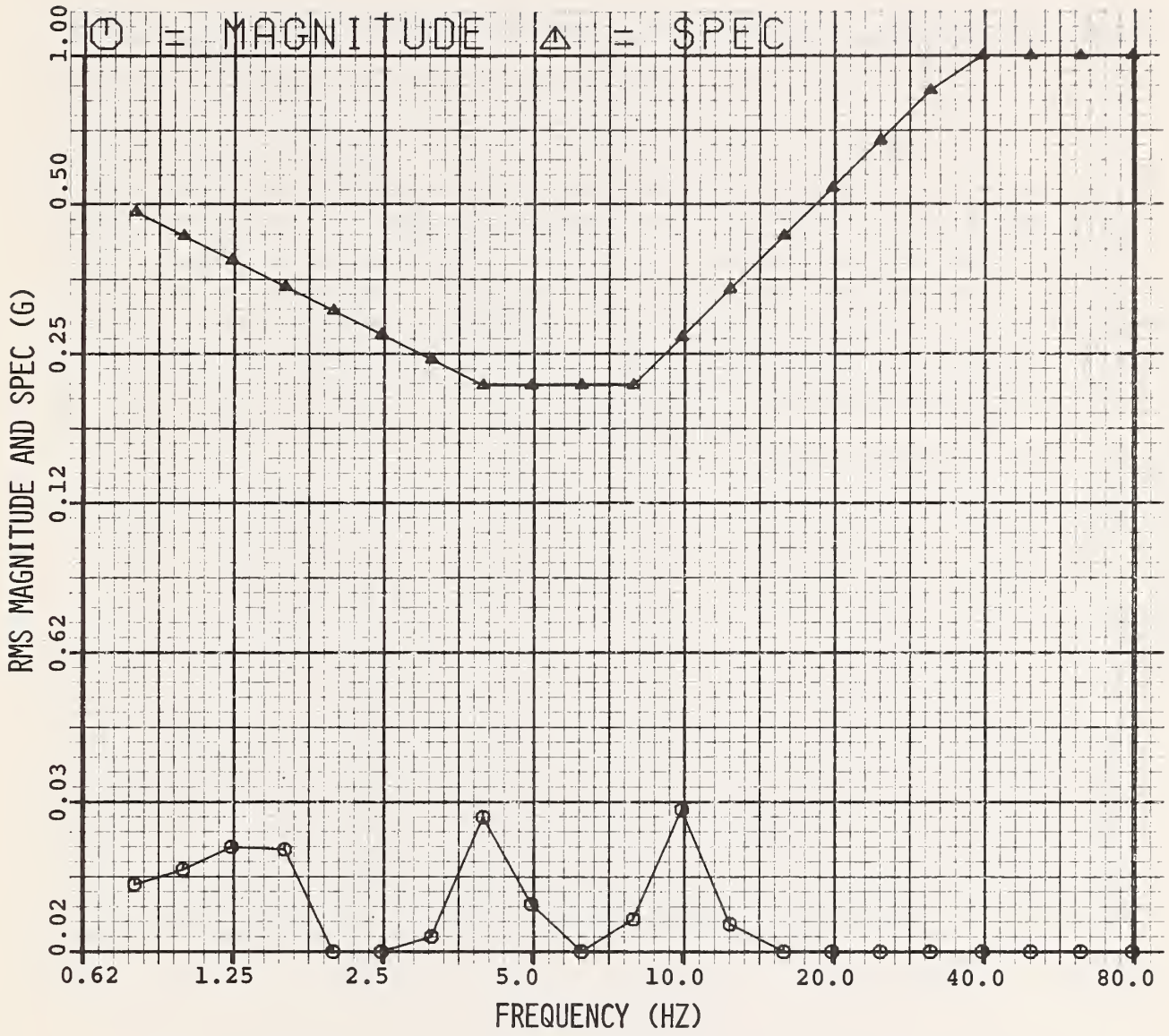


Figure C-4. ASL Driver Vertical Acceleration, Light Load (Wheelchair Passenger), 30 mph.

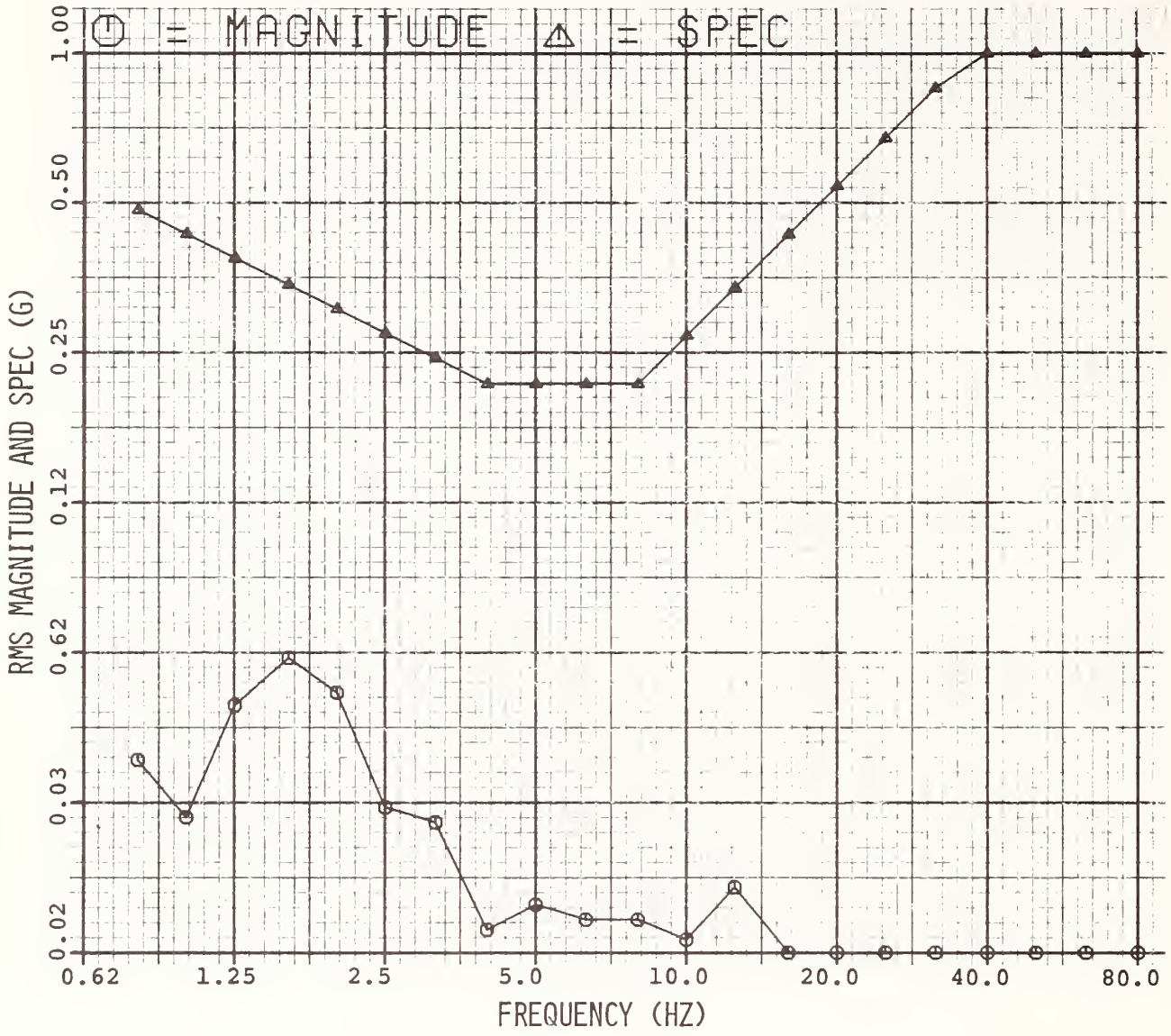


Figure C-5. ASL Driver Vertical Acceleration, Light Load (Wheelchair Passenger), 40 mph.

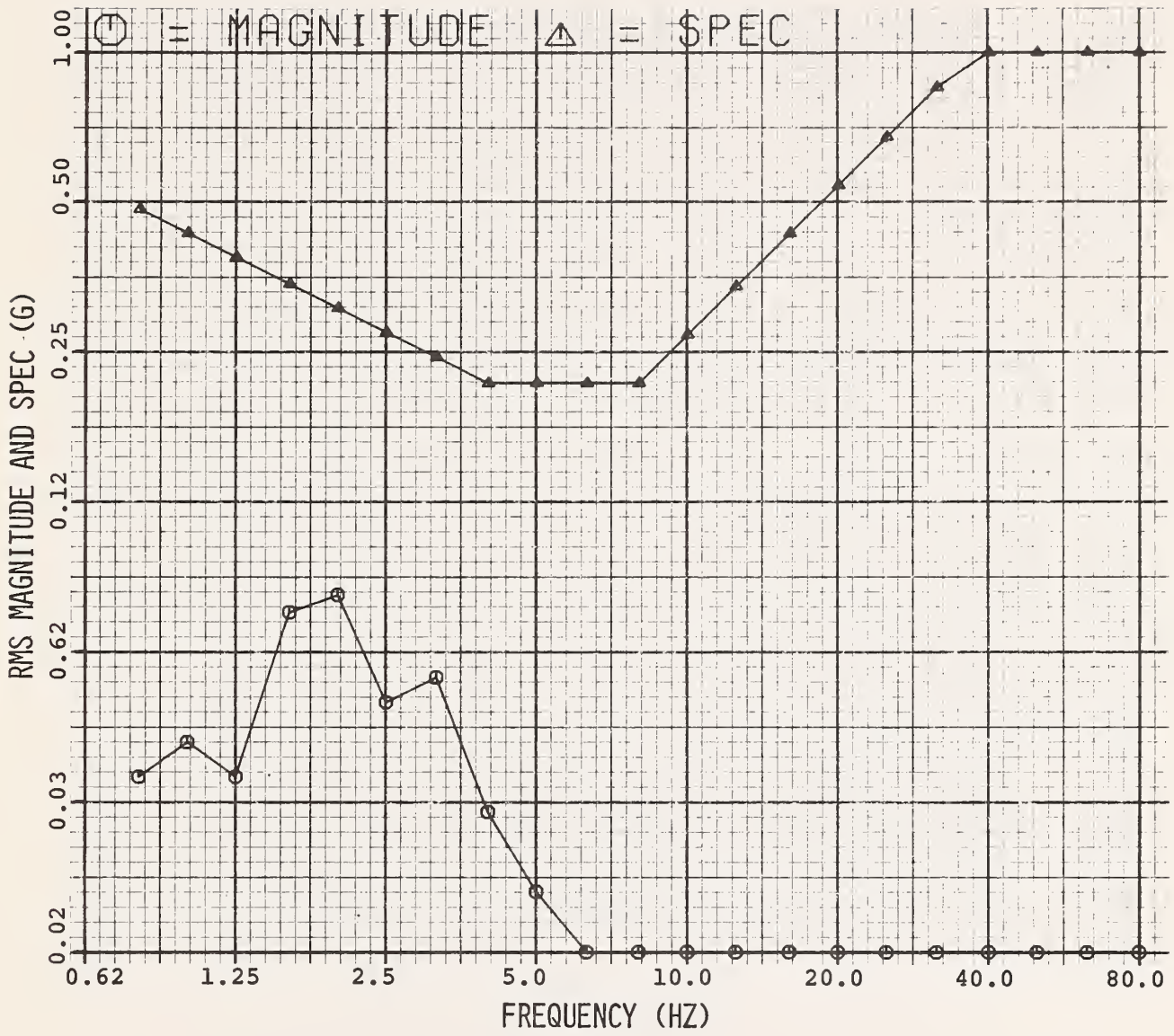


Figure C-6. ASL Driver Vertical Acceleration, Light Load (Rear Seat Passenger), 5 mph.

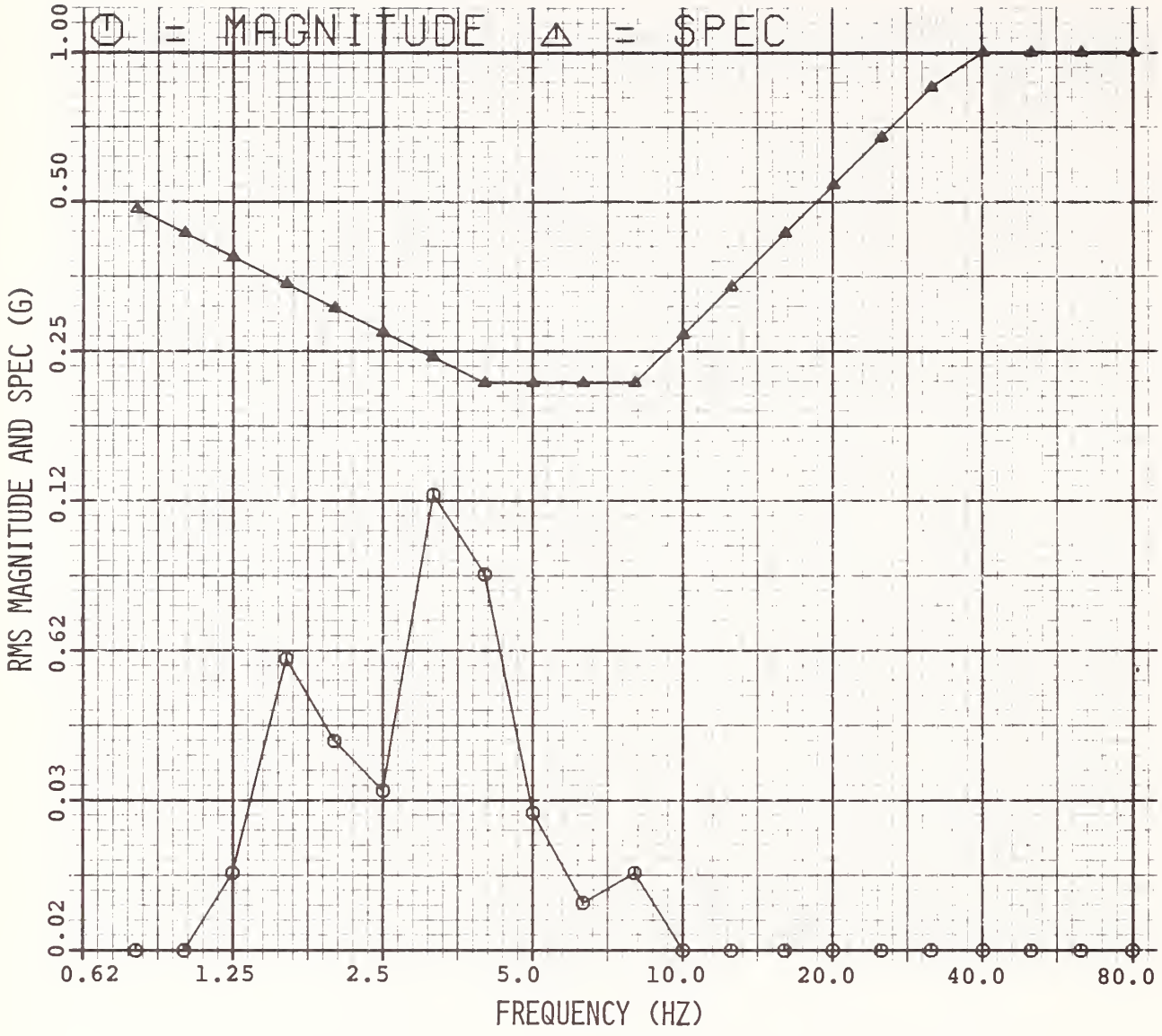


Figure C-7. ASL Driver Vertical Acceleration, Light Load, (Rear Seat Passenger), 10 mph.

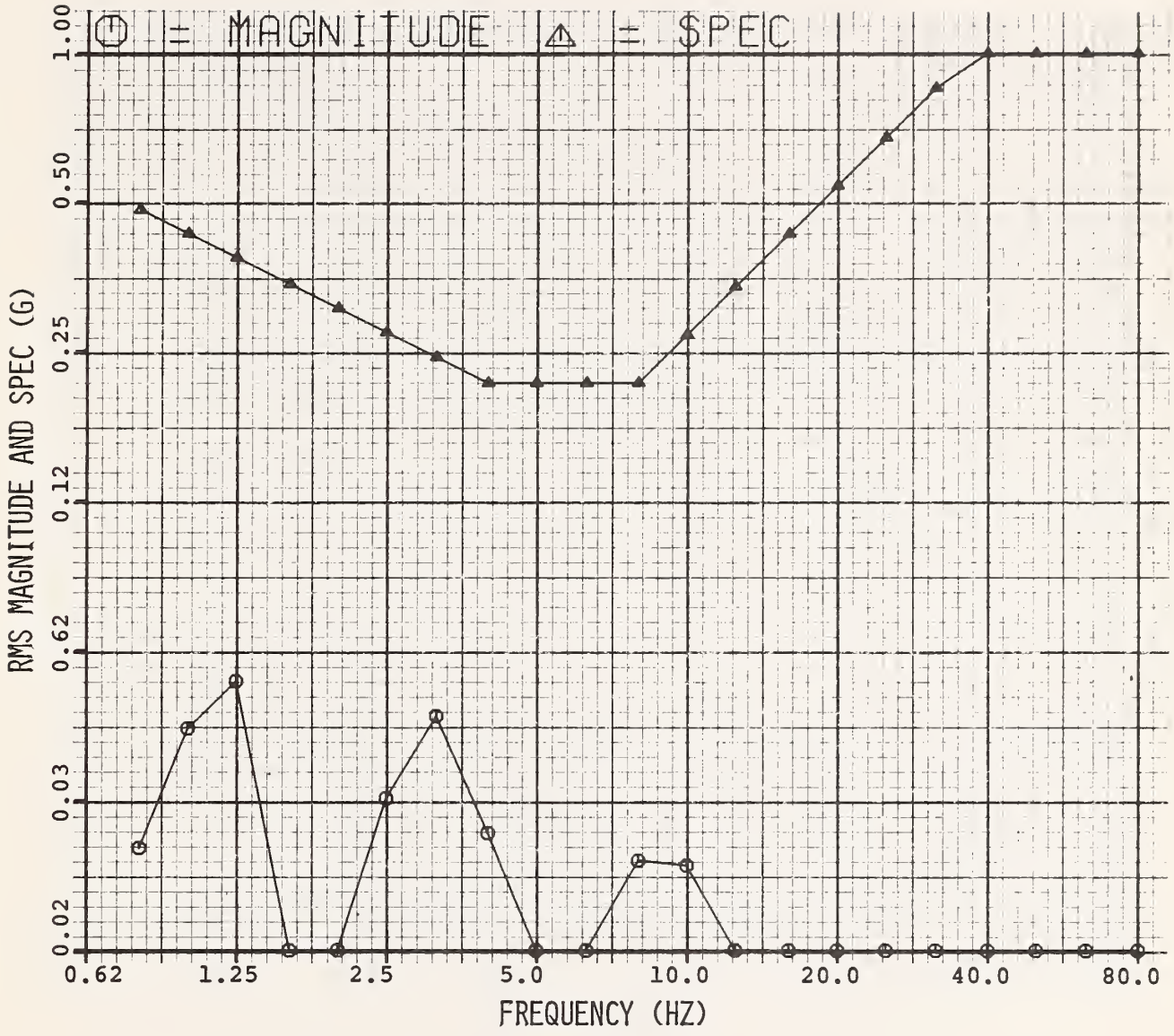


Figure C-8. ASL Driver Vertical Acceleration, Light Load (Rear Seat Passenger), 20 mph.

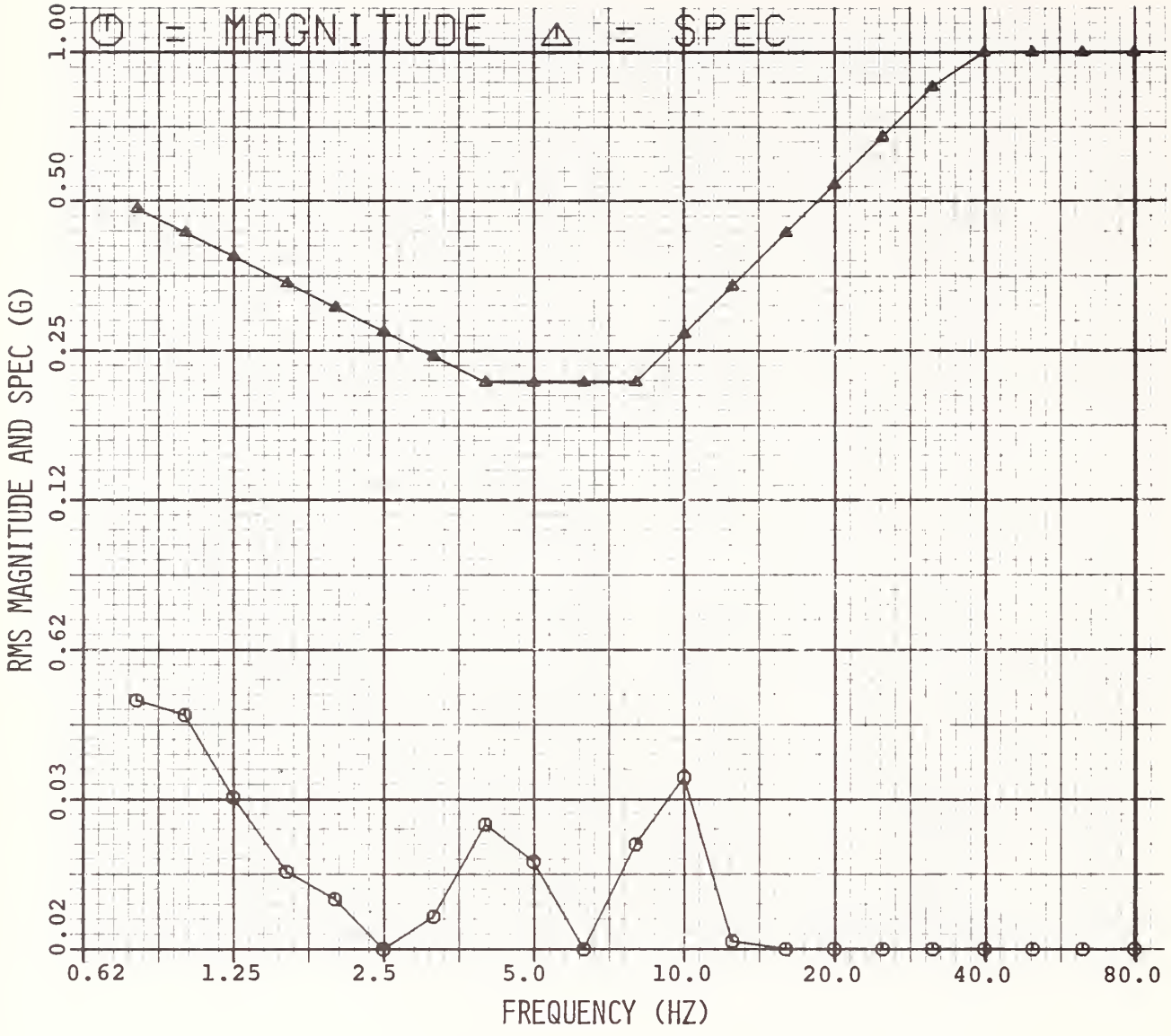


Figure C-9. ASL Driver Vertical Acceleration, Light Load (Rear Seat Passenger), 30 mph.

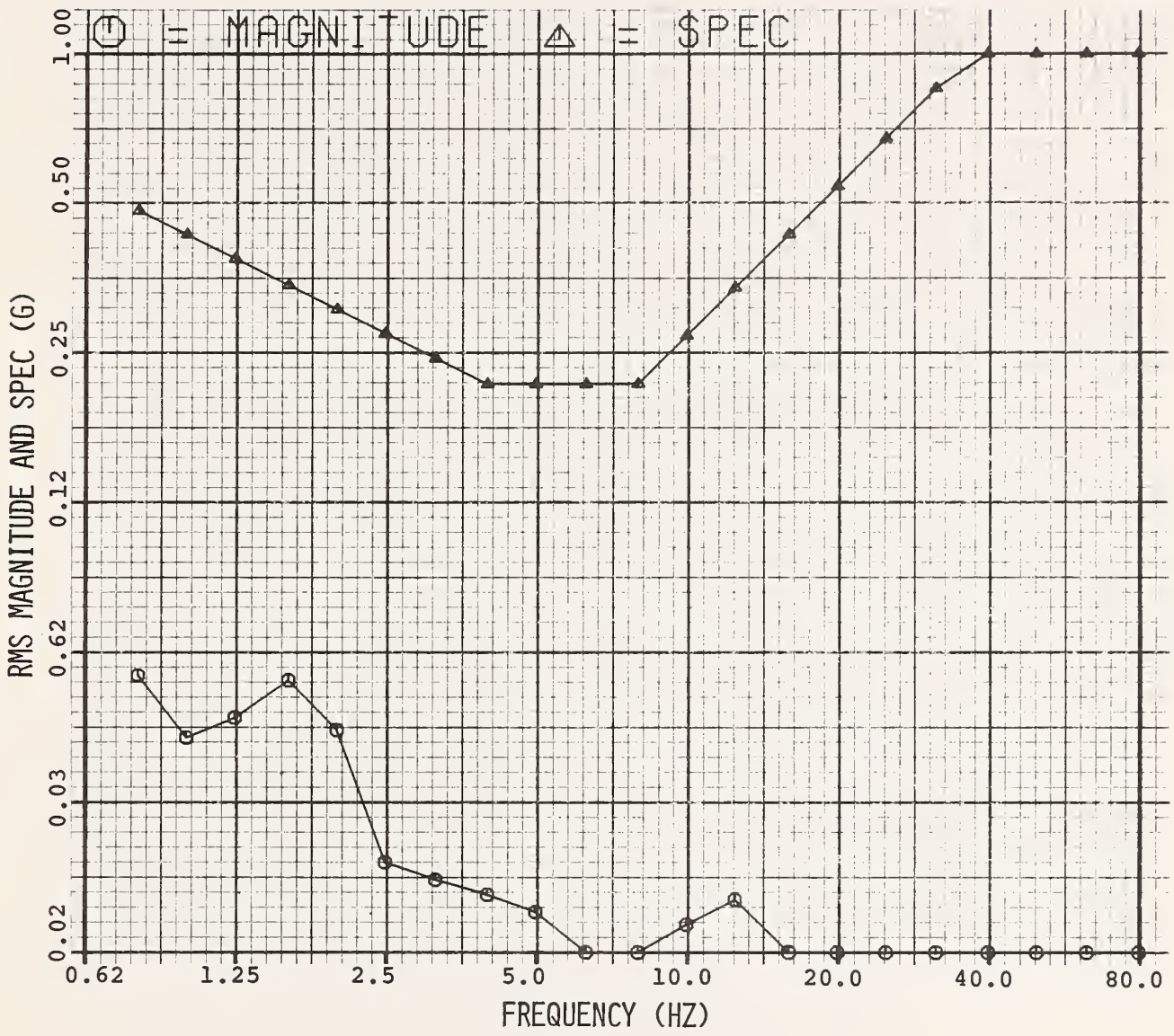


Figure C-10. ASL Driver Vertical Acceleration, Light Load (Rear Seat Passenger), 40 mph.

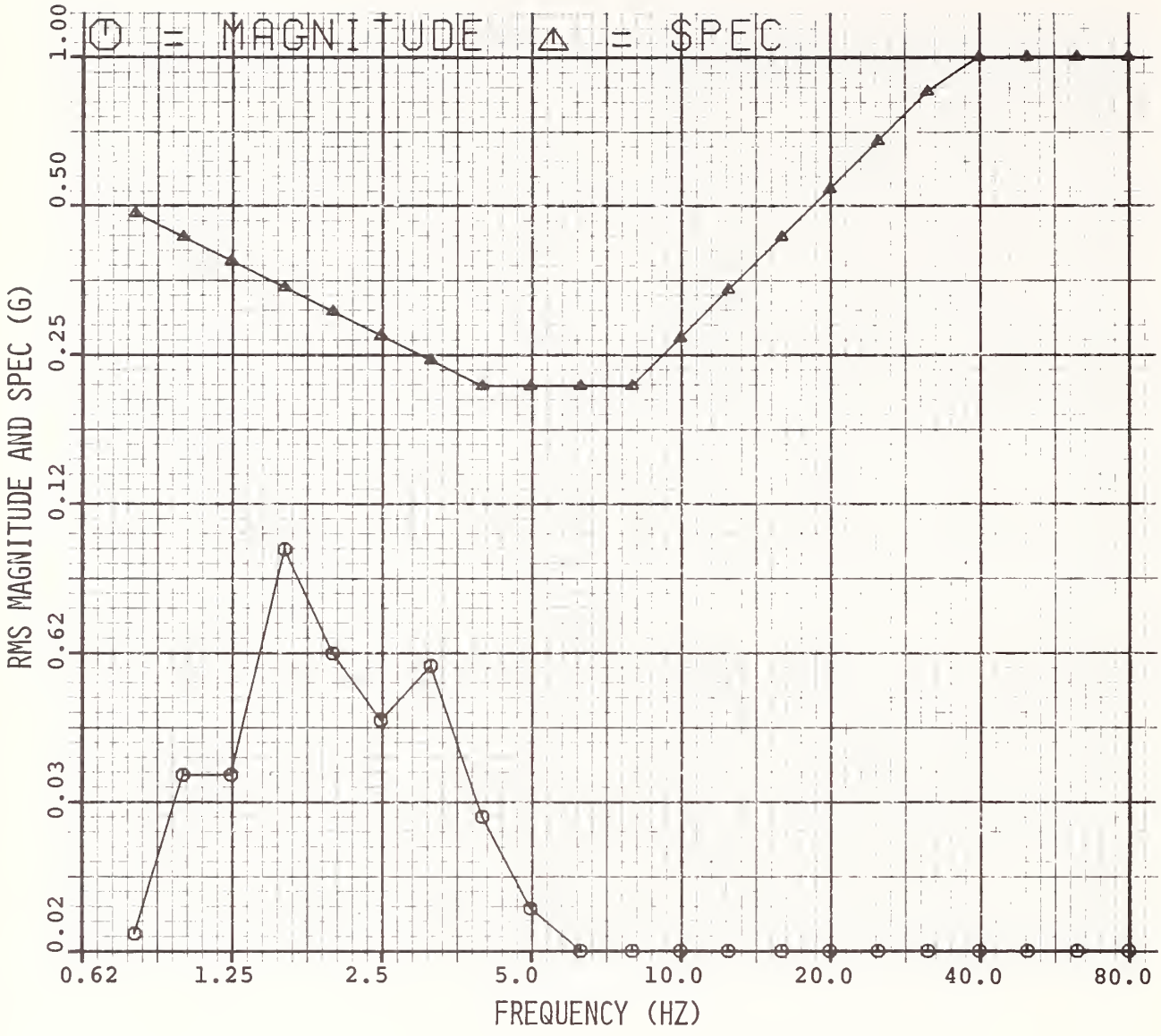


Figure C-11. ASL Driver Vertical Acceleration, Heavy Load, 5 mph.

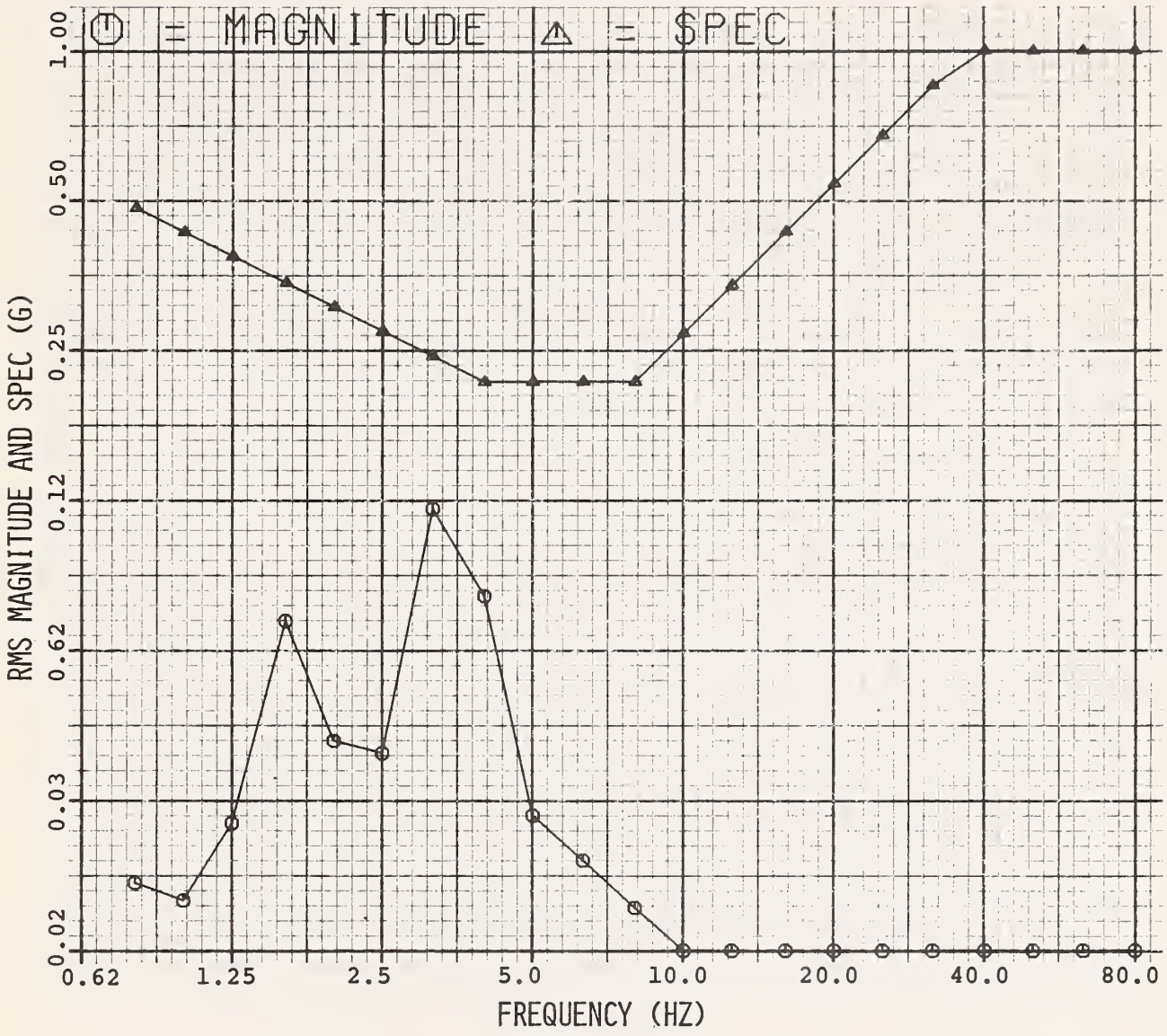


Figure C-12. ASL Driver Vertical Acceleration, Heavy Load, 10 mph.

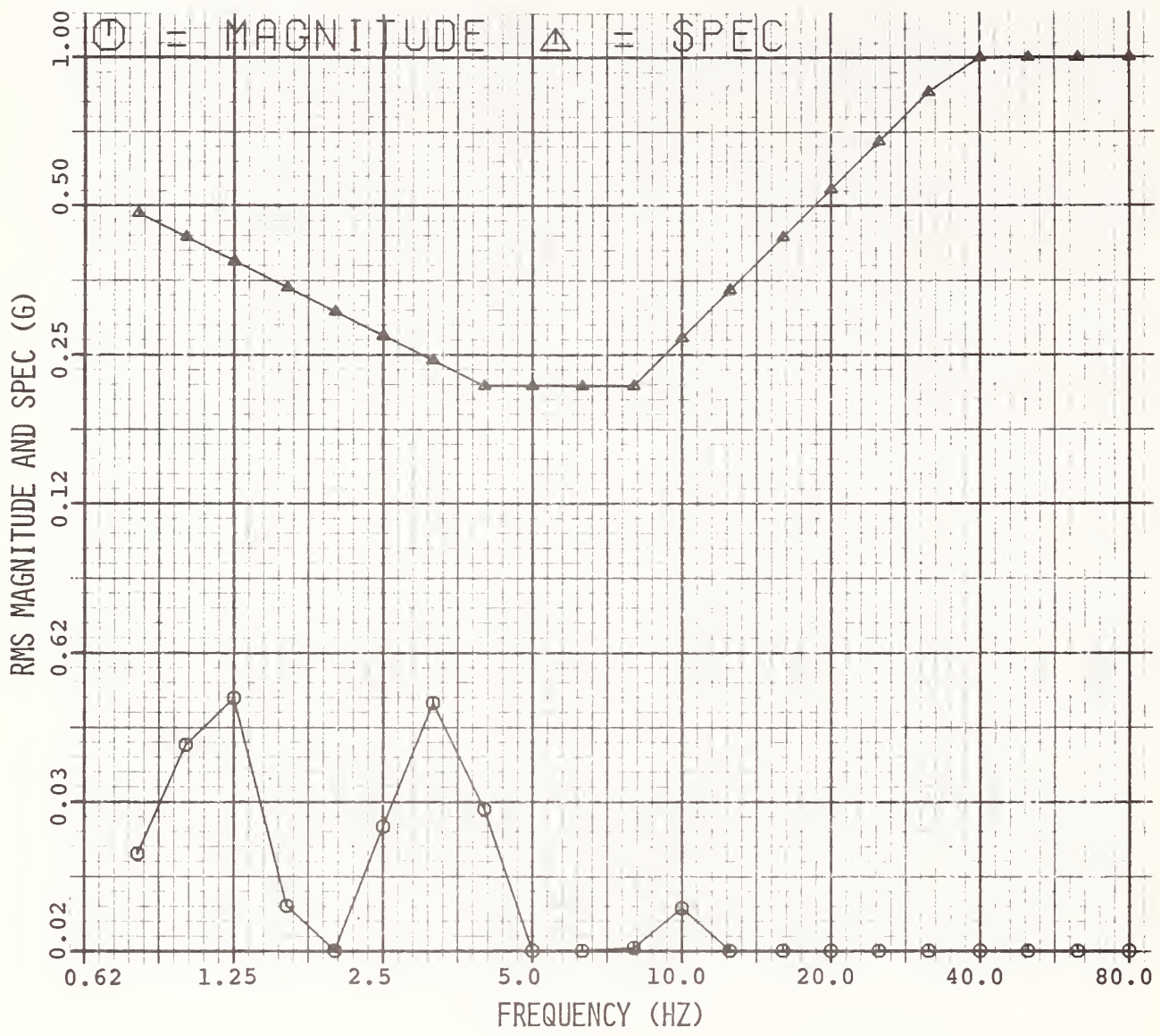


Figure C-13. ASL Driver Vertical Acceleration, Heavy Load, 20 mph.

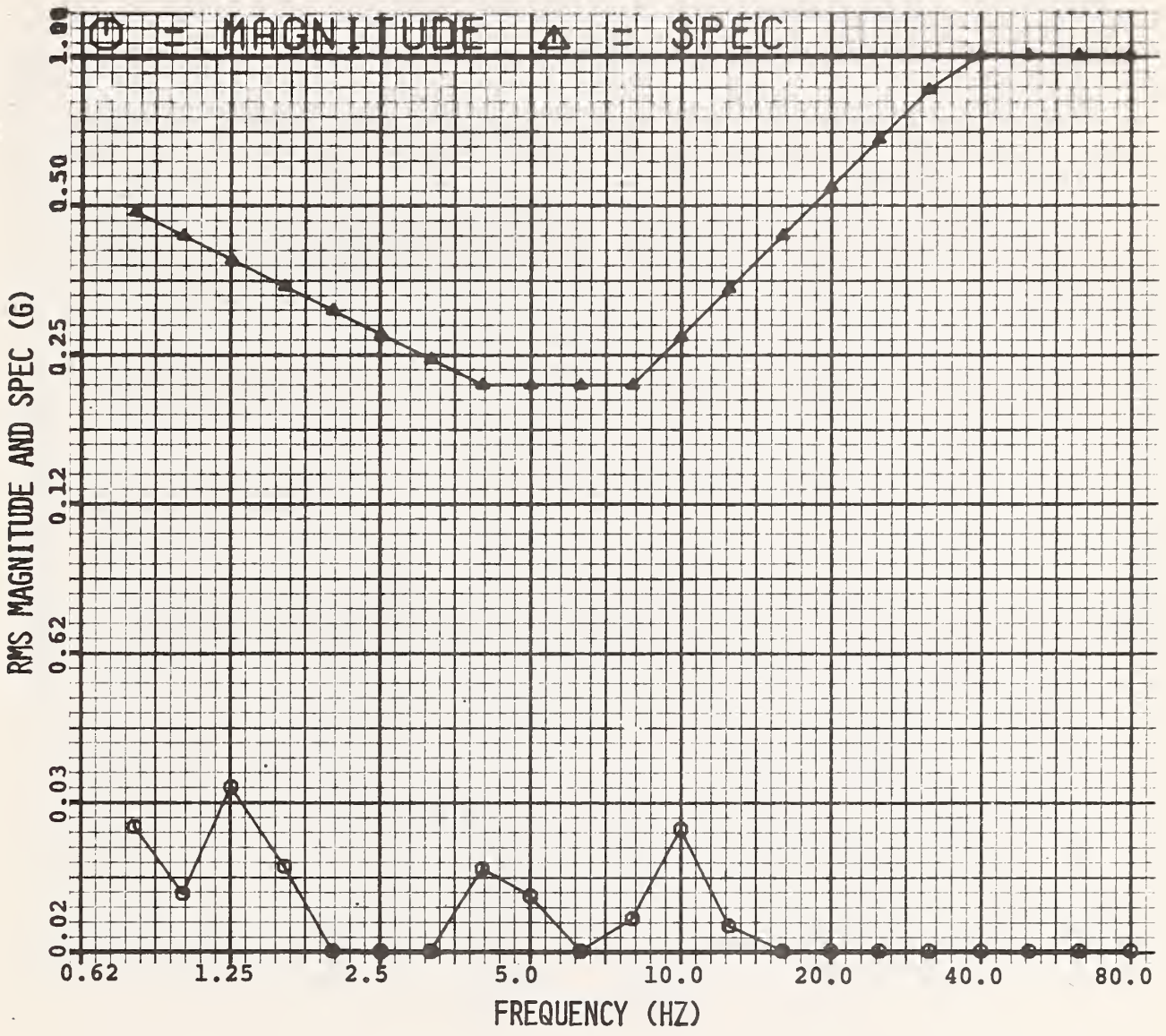


Figure C-14. ASL Driver Vertical Acceleration, Heavy Load, 30 mph.

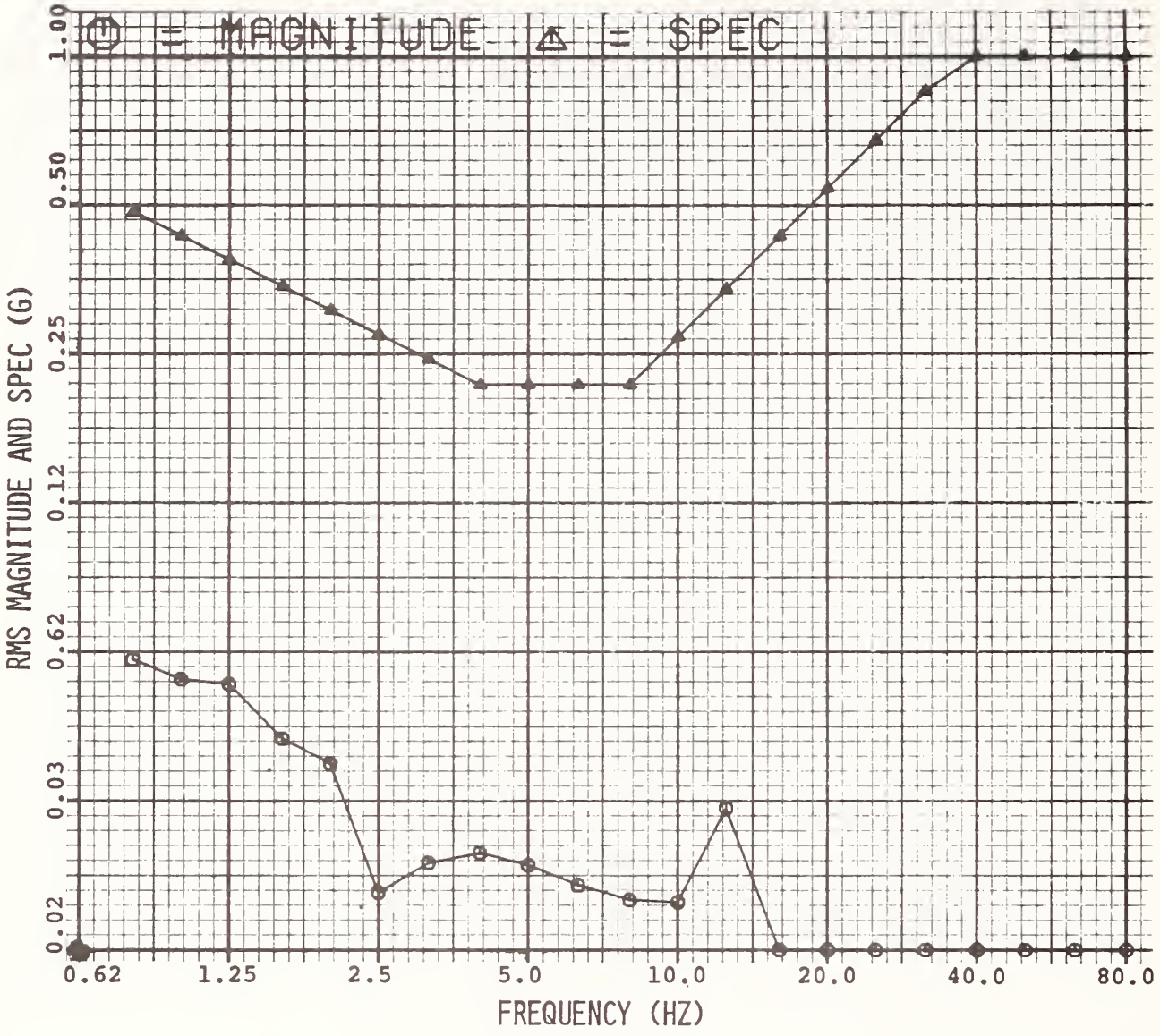


Figure C-15. ASL Driver Vertical Acceleration, Heavy Load, 40 mph.

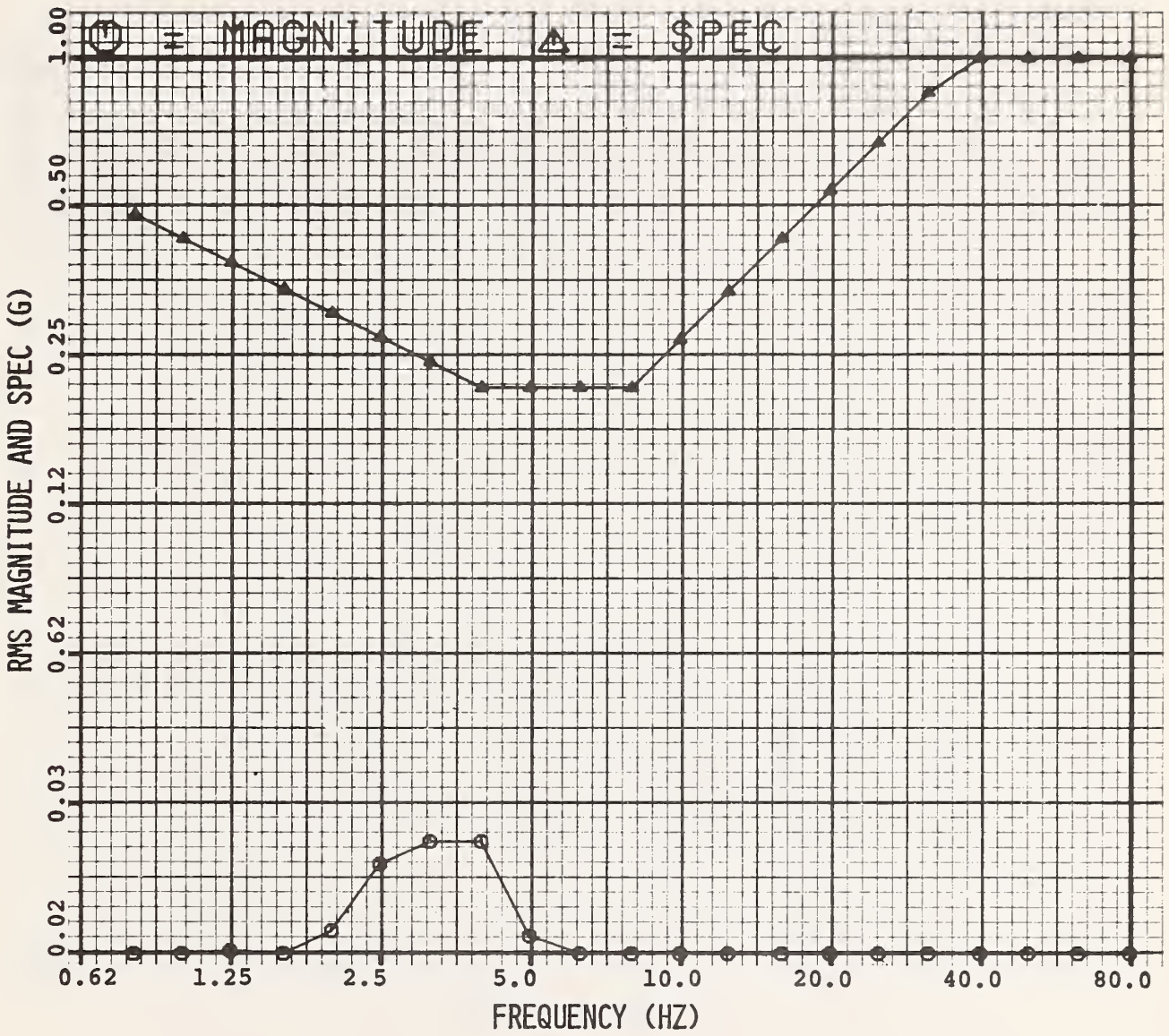


Figure C-16. ASL Driver Vertical Acceleration, Urban Driving Course.

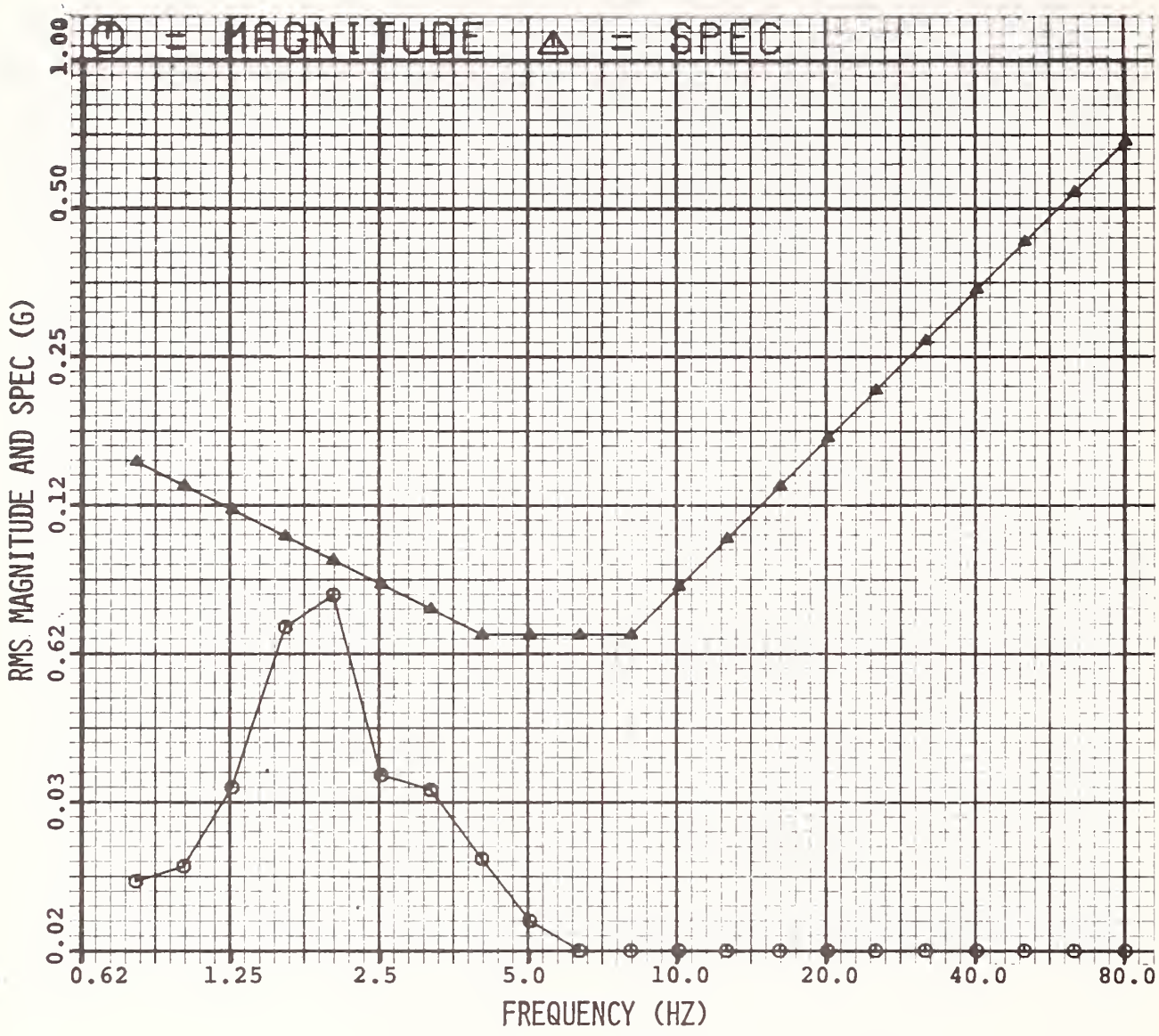


Figure C-17. ASL Wheelchair Passenger Vertical Acceleration, Light Load, 5 mph.

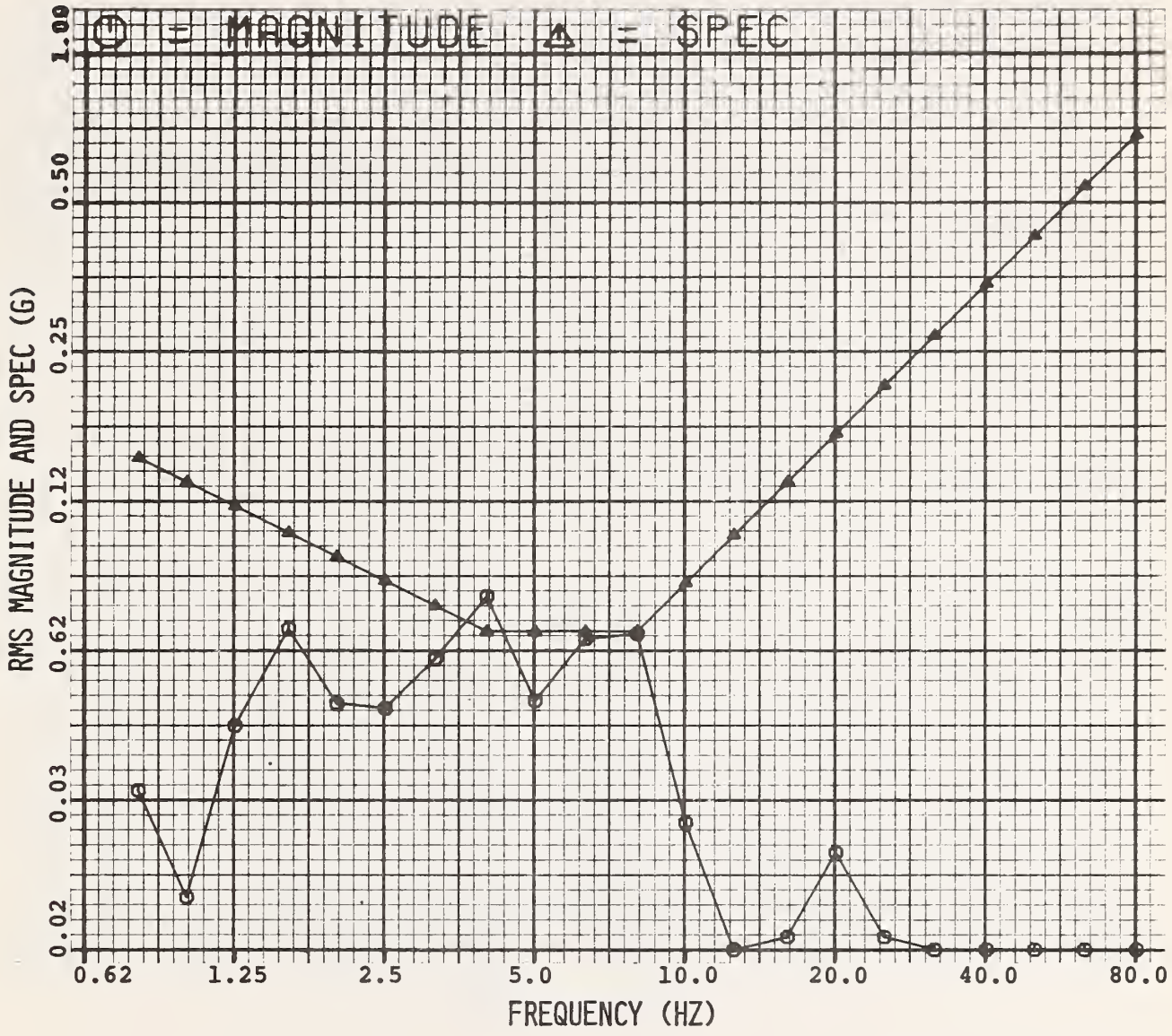


Figure C-18. ASL Wheelchair Passenger Vertical Acceleration, Light Load, 10 mph.

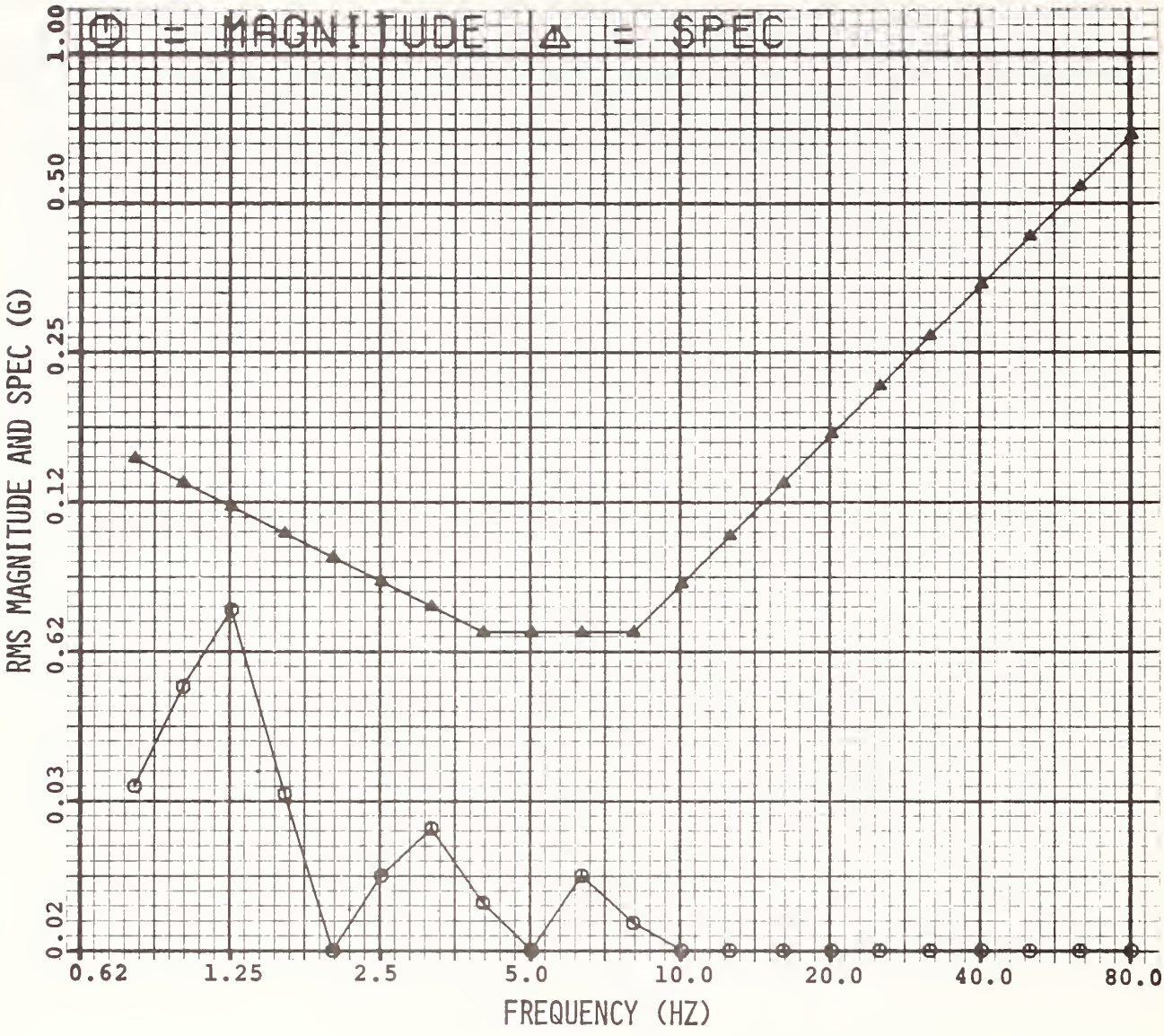


Figure C-19. ASL Wheelchair Passenger Vertical Acceleration, Light Load, 20 mph.

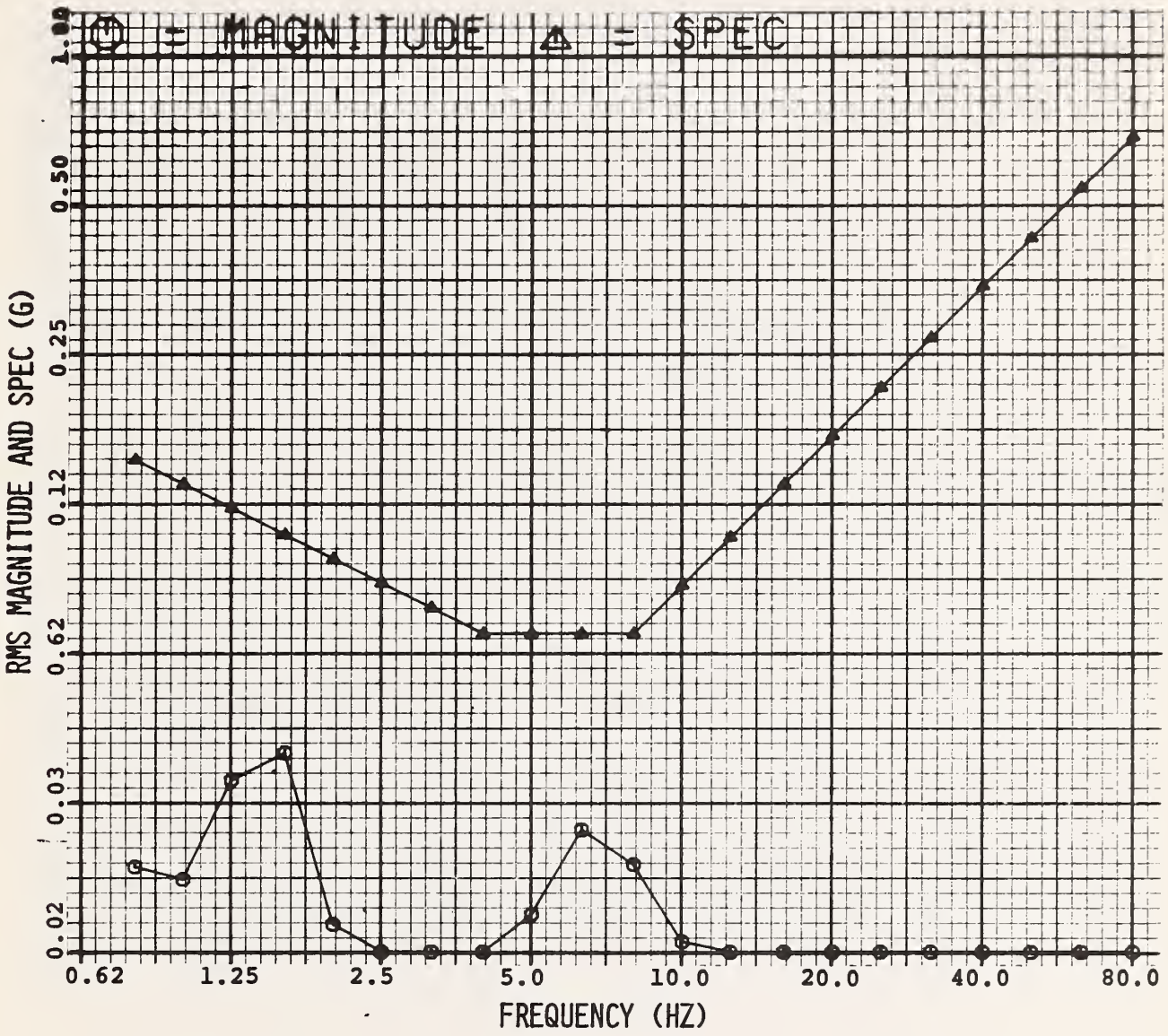


Figure C-20. ASL Wheelchair Passenger Vertical Acceleration, Light Load, 30 mph.

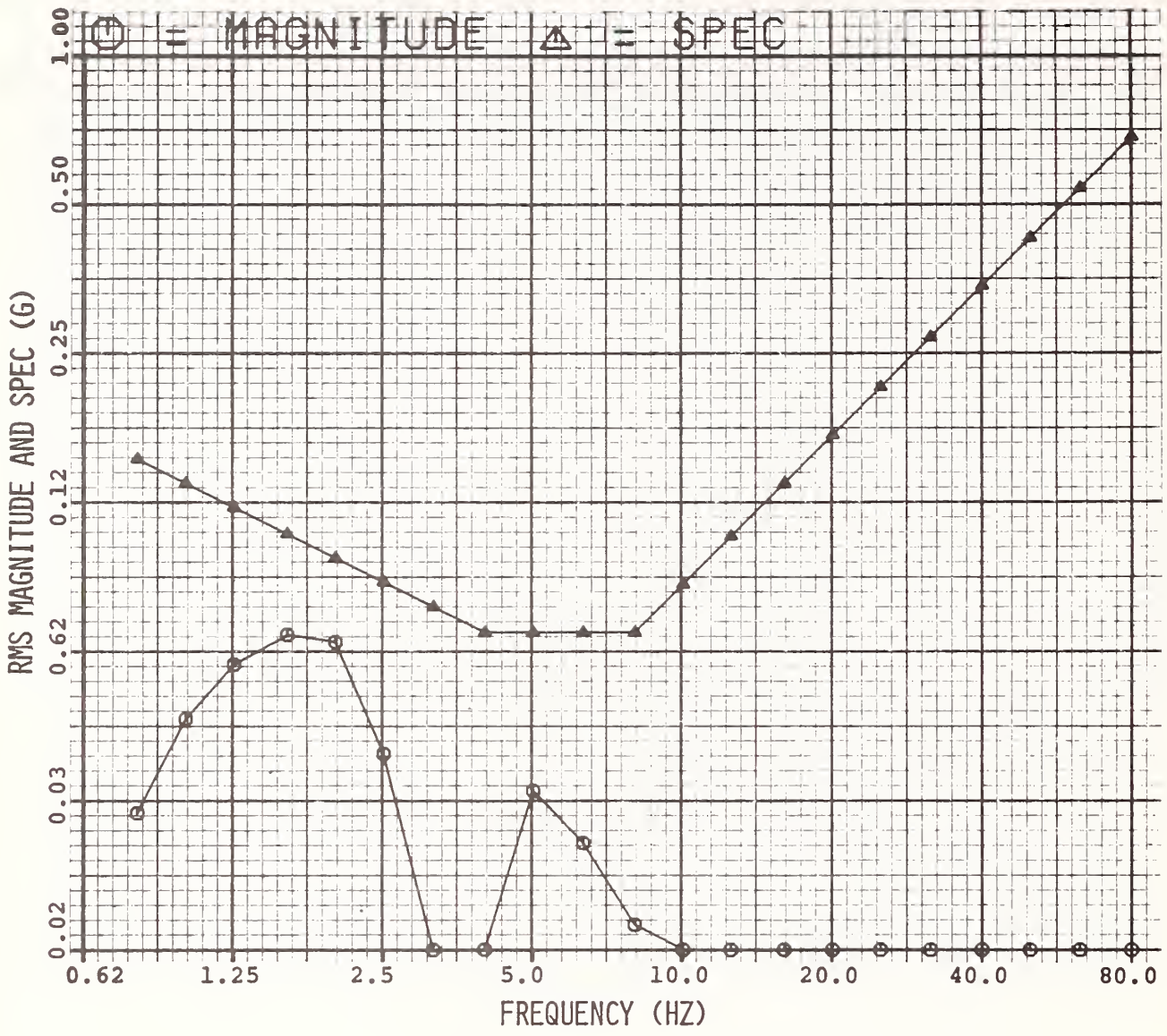


Figure C-21. ASL Wheelchair Passenger Vertical Acceleration, Light Load, 40 mph.

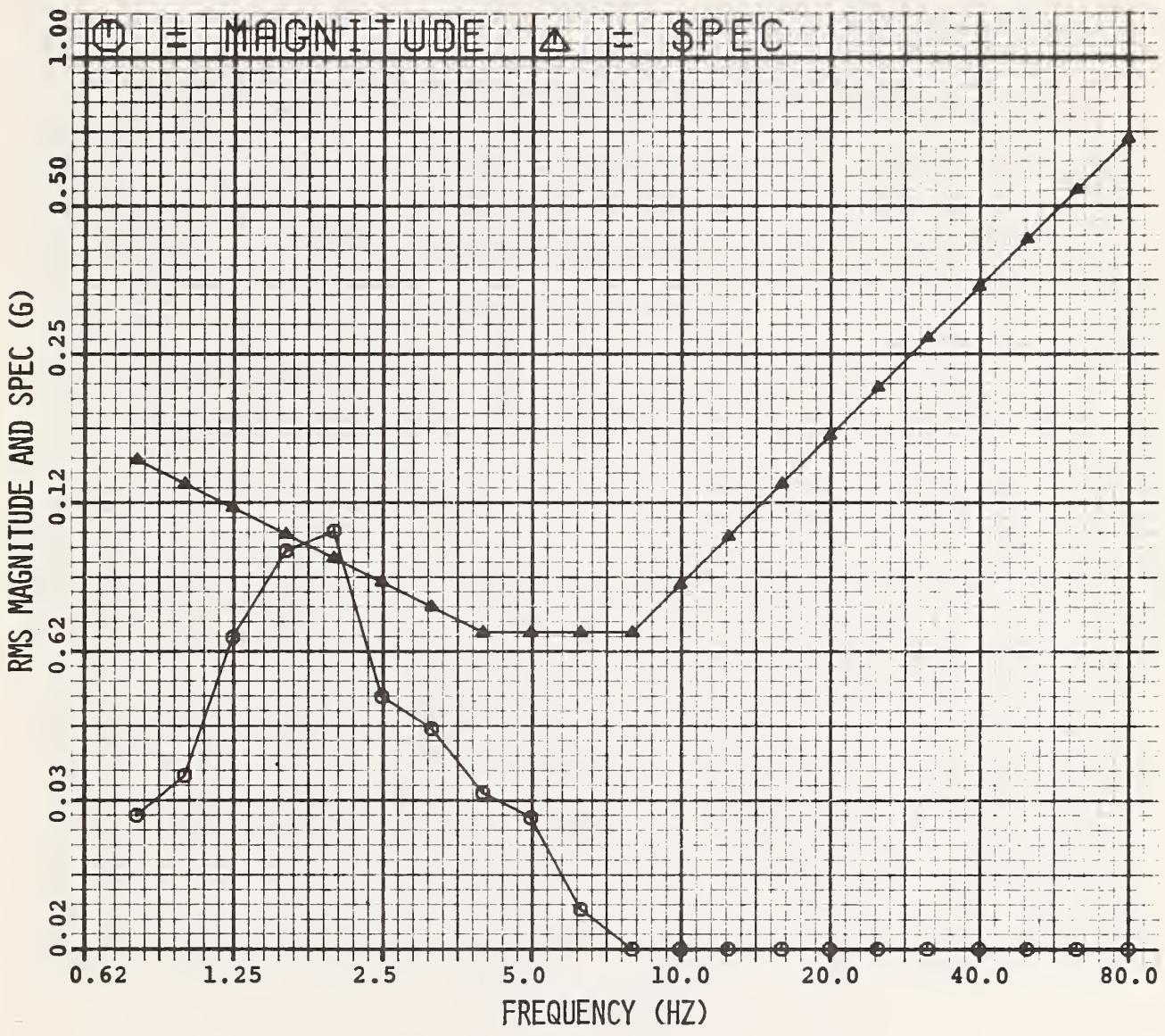


Figure C-22. ASL Rear Seat Passenger Vertical Acceleration, Light Load, 5 mph.

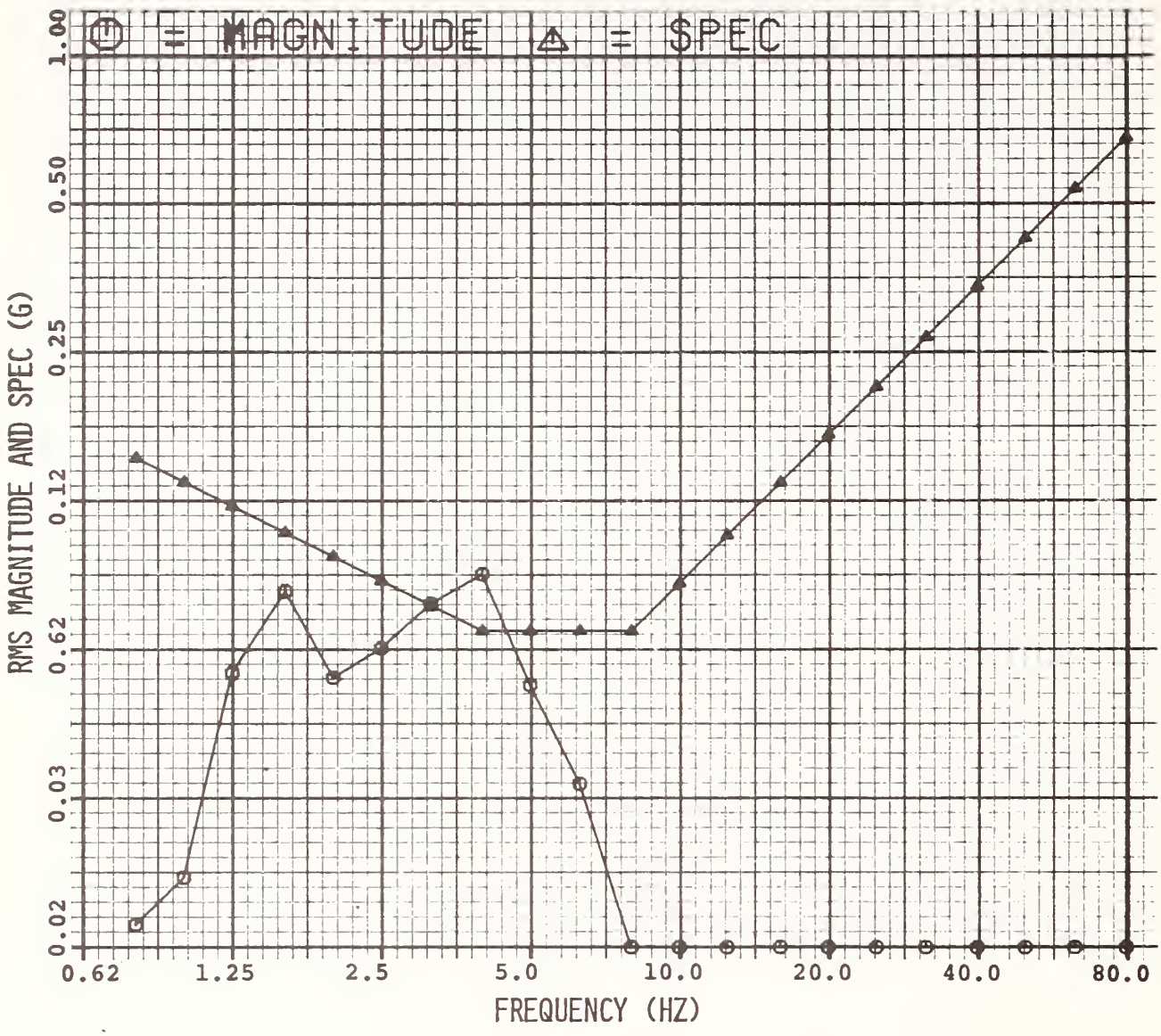


Figure C-23. ASL Rear Seat Passenger Vertical Acceleration, Light Load, 10 mph.

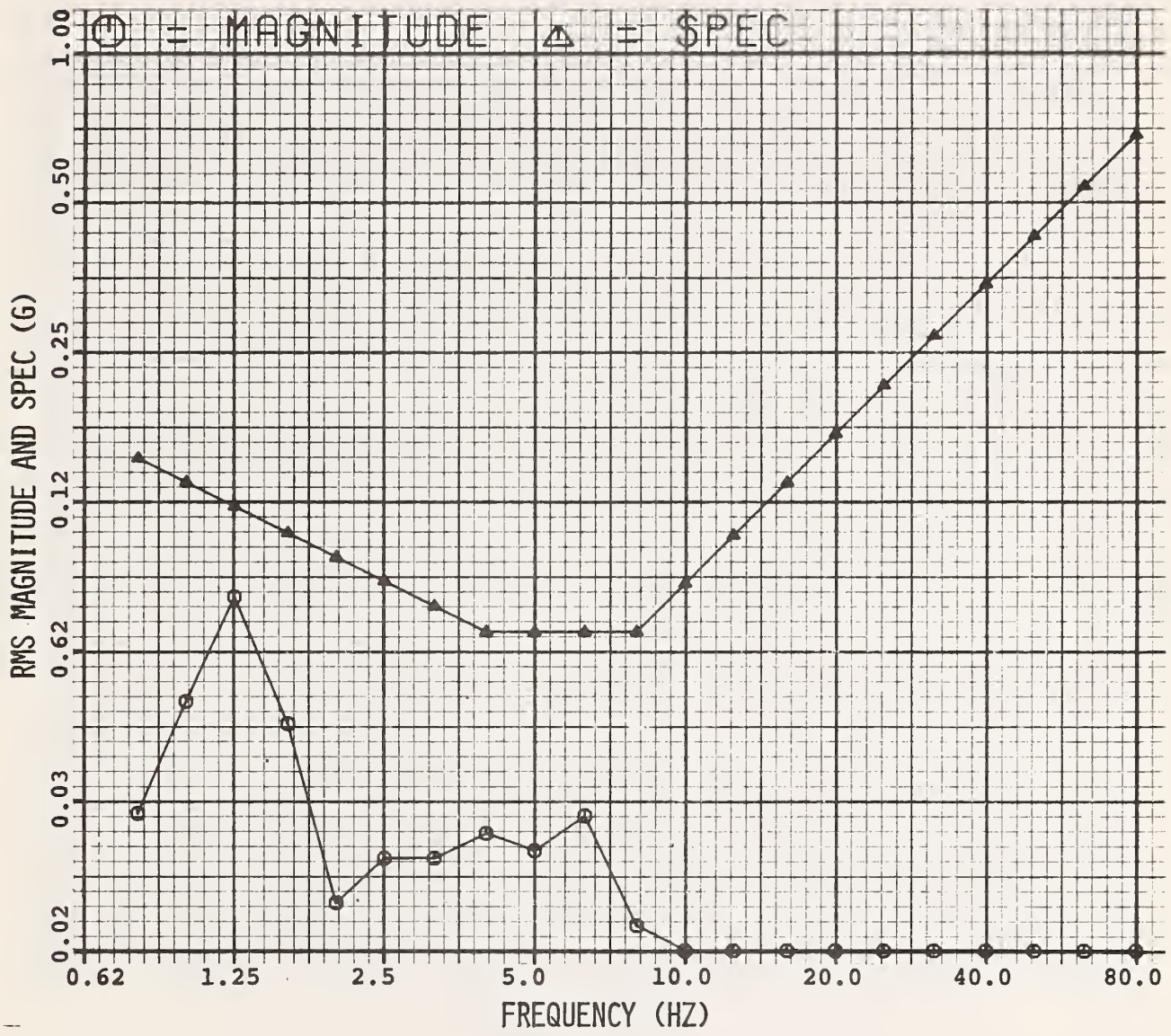


Figure C-24. ASL Rear Seat Passenger Vertical Acceleration, Light Load, 20 mph.

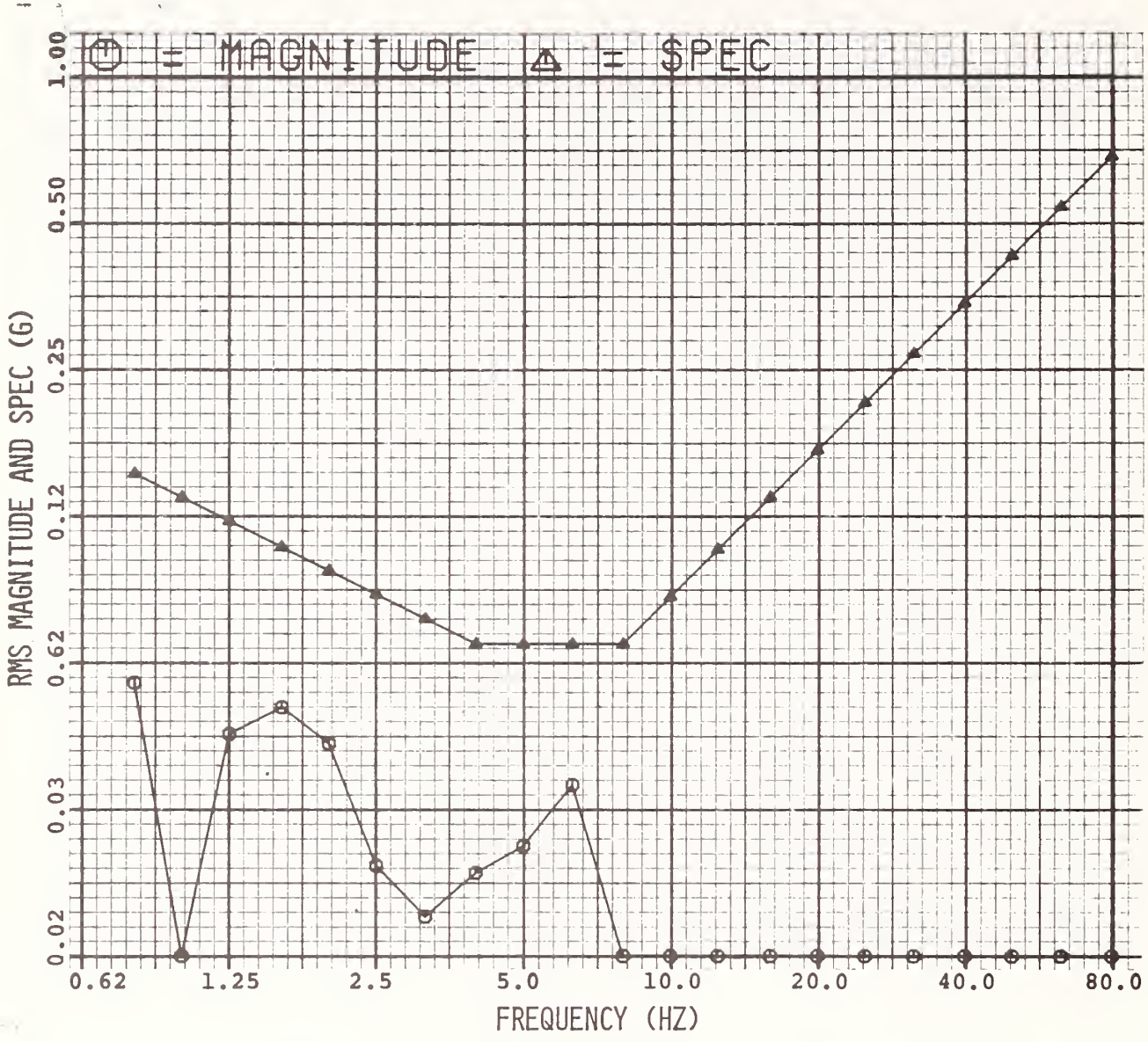


Figure C-25. ASL Rear Seat Passenger Vertical Acceleration, Light Load, 30 mph.

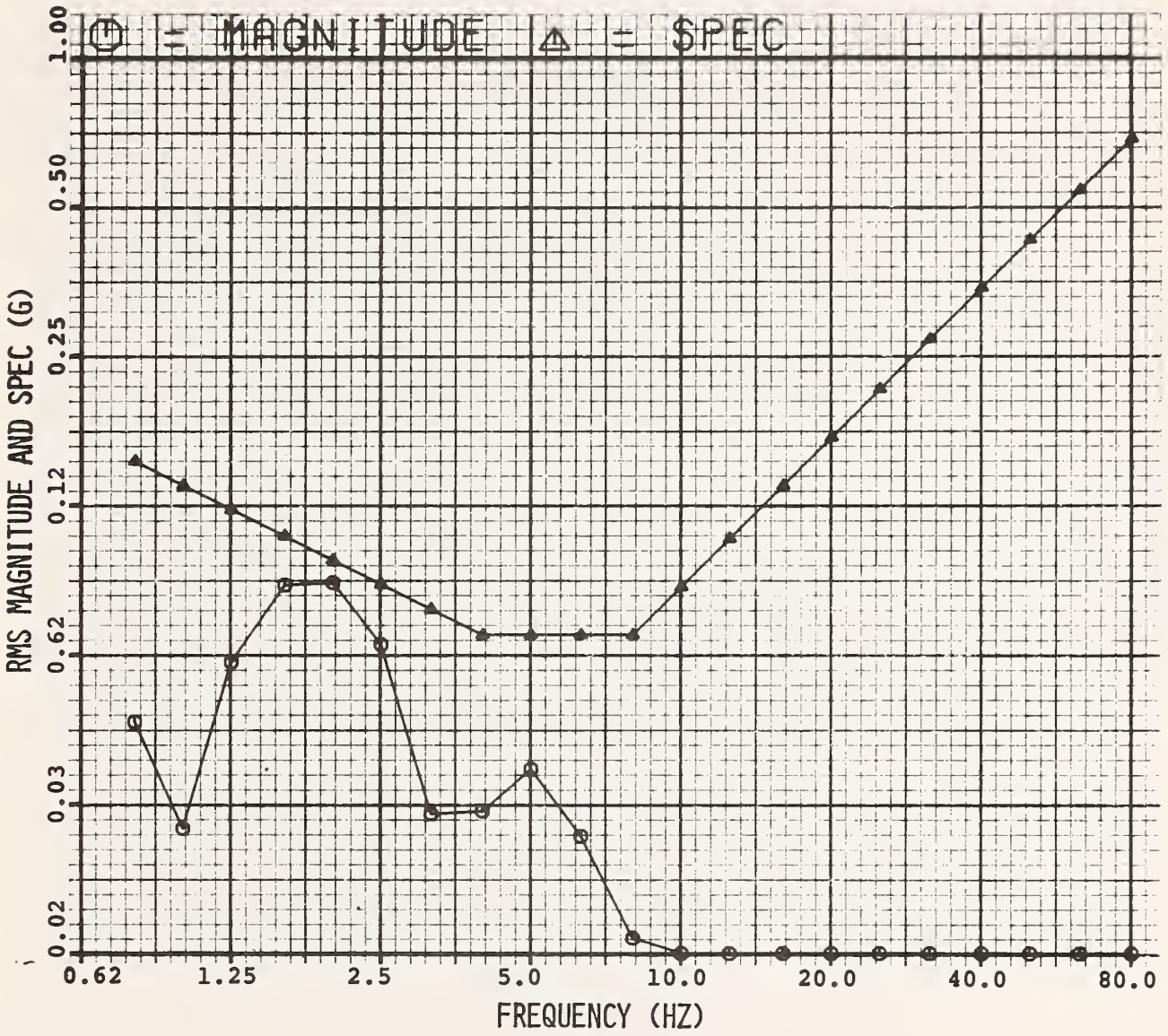


Figure C-26. ASL Rear Seat Passenger Vertical Acceleration, Light Load, 40 mph.

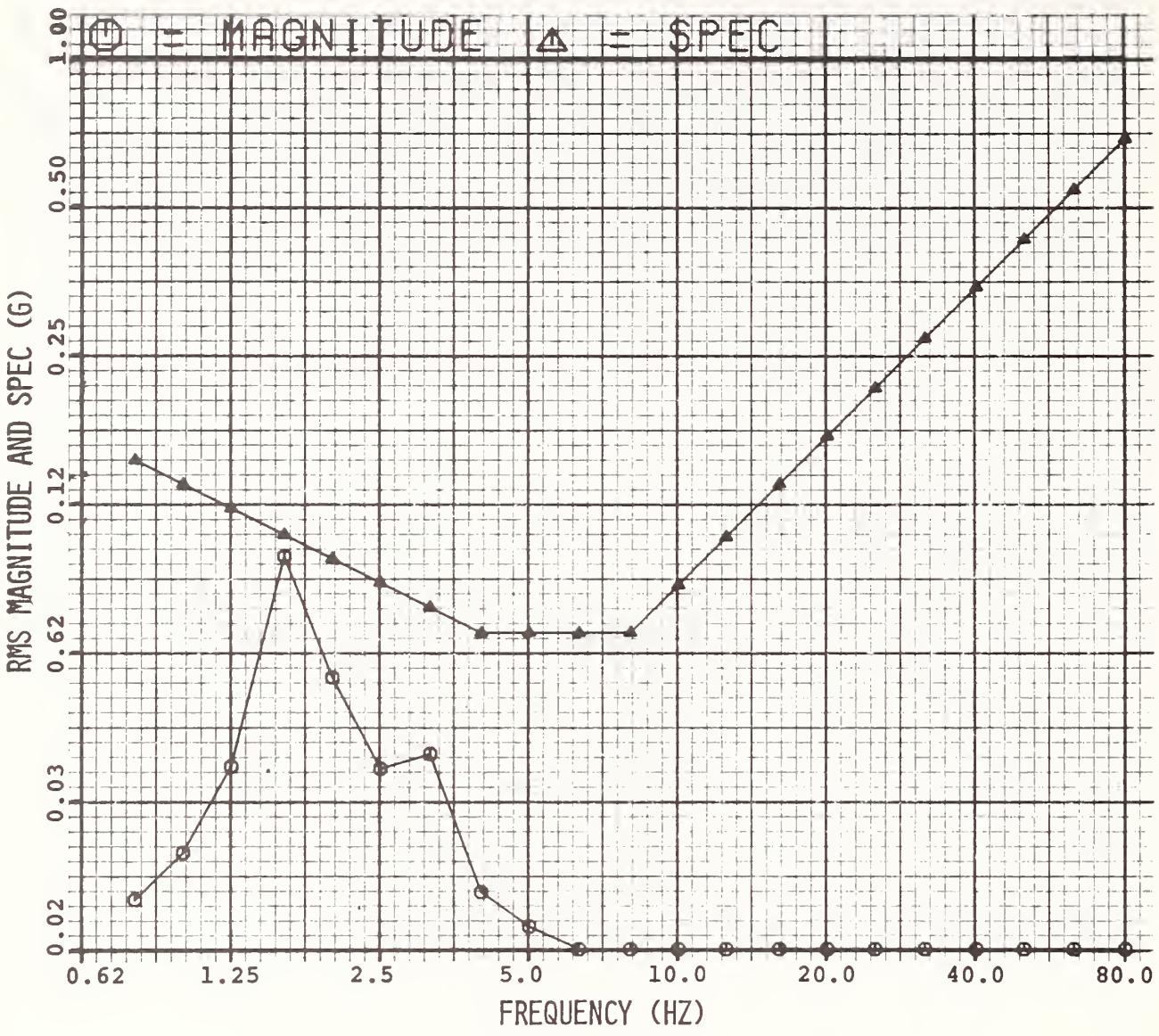


Figure C-27. ASL Wheelchair Passenger Vertical Acceleration, Heavy Load, 5 mph.

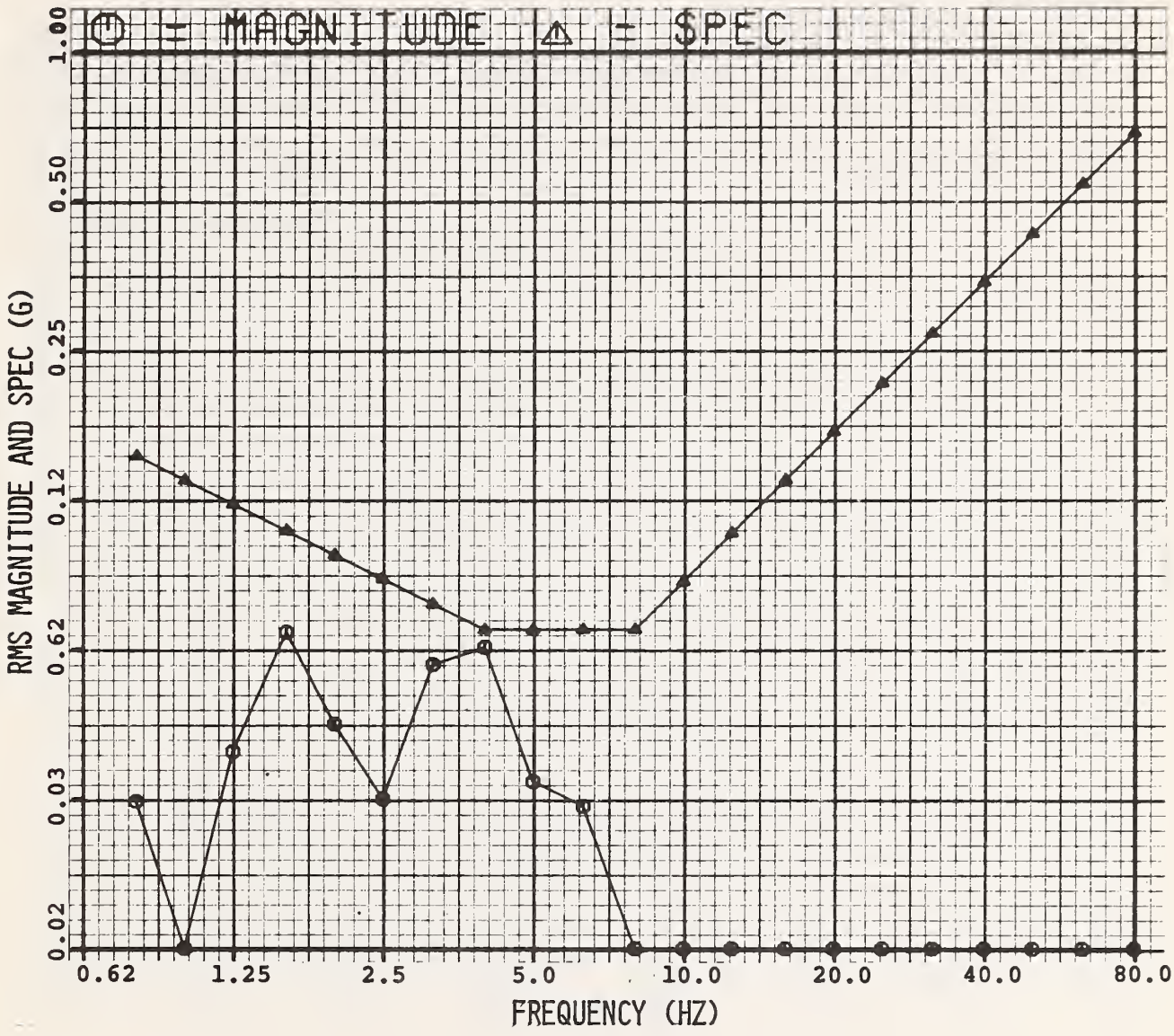


Figure C-28. ASL Wheelchair Passenger Vertical Acceleration, Heavy Load, 10 mph.

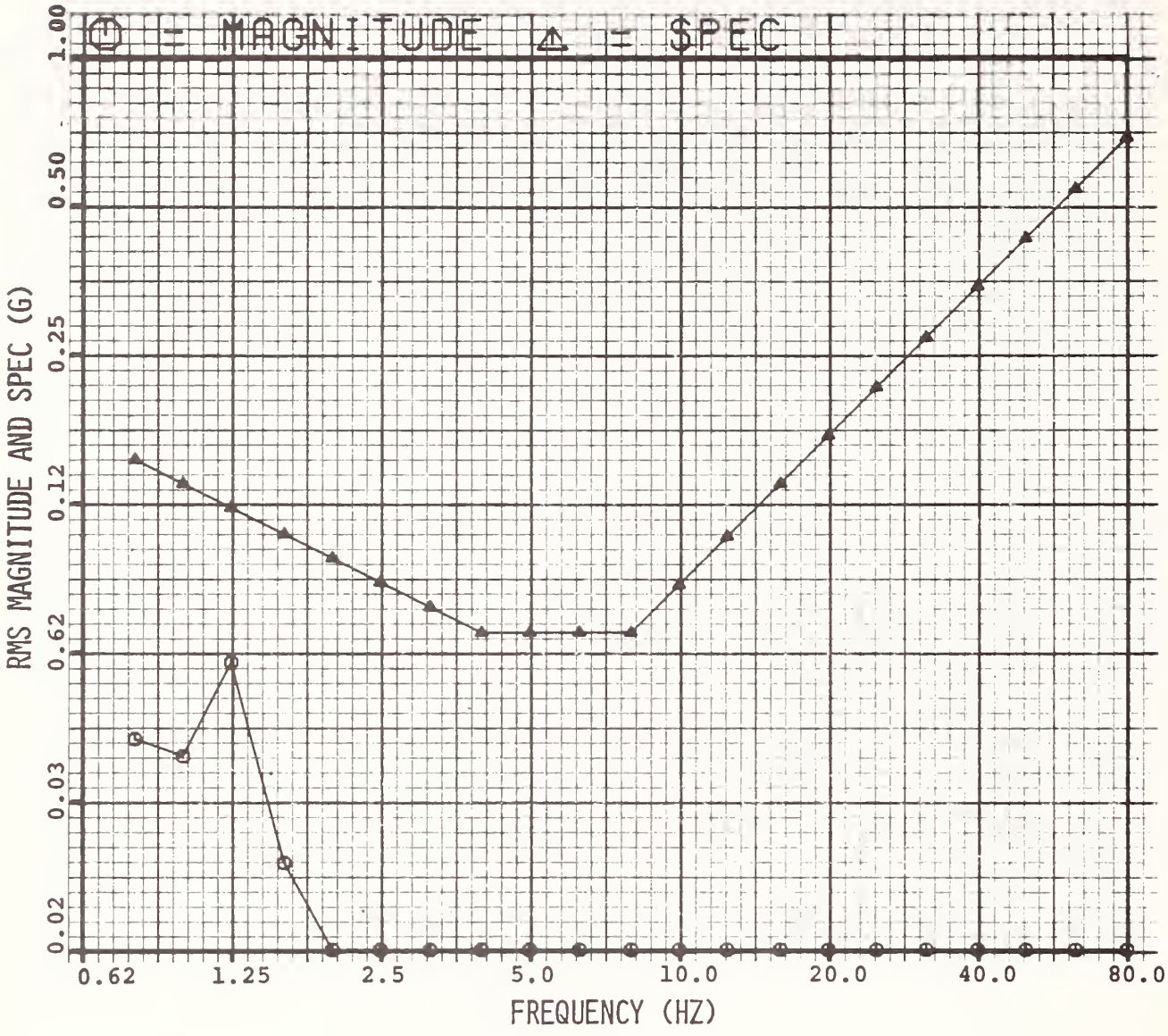


Figure C-29. ASL Wheelchair Passenger Vertical Acceleration, Heavy Load, 20 mph.

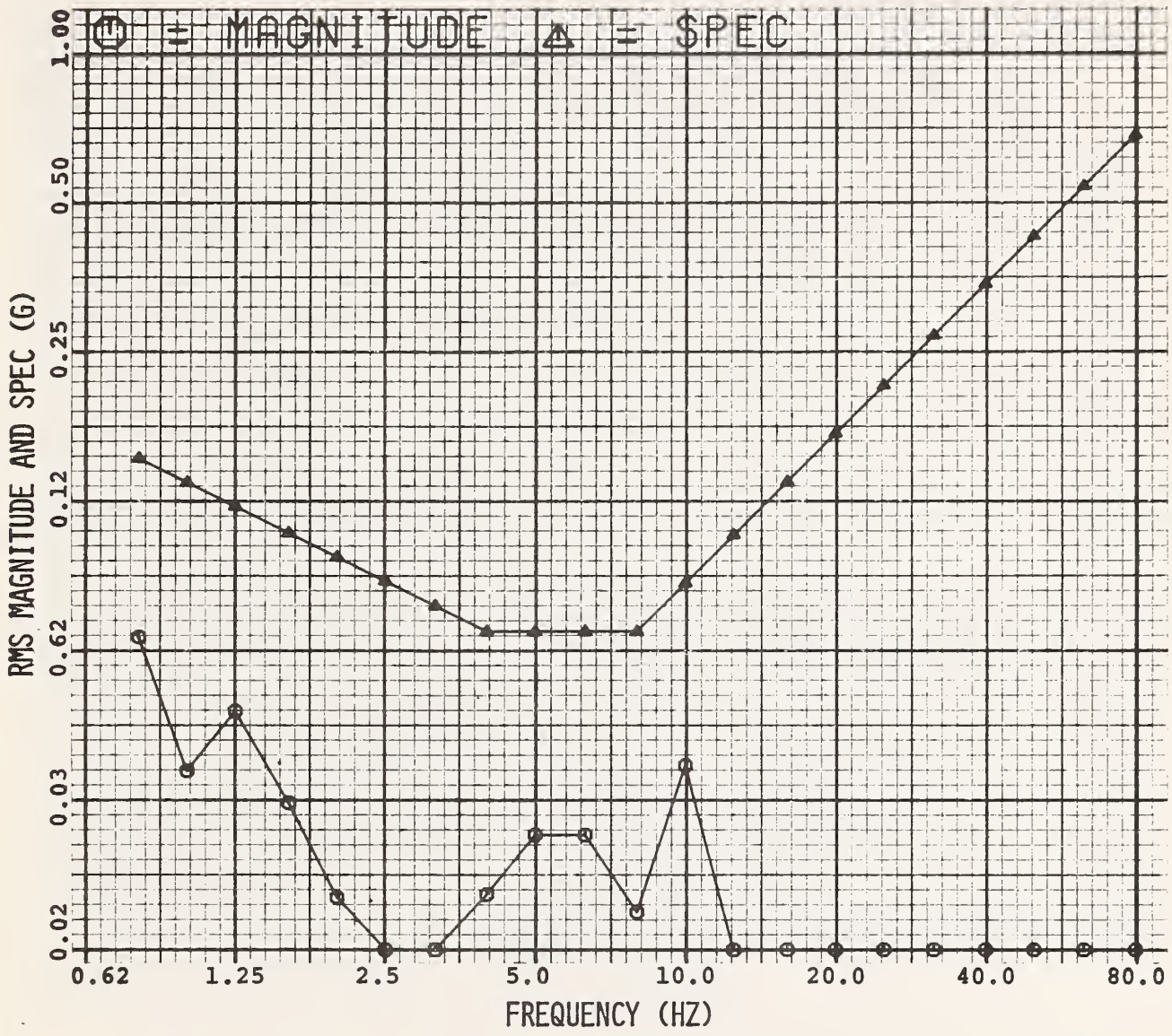


Figure C-30. ASL Wheelchair Passenger Vertical Acceleration, Heavy Load, 30 mph.

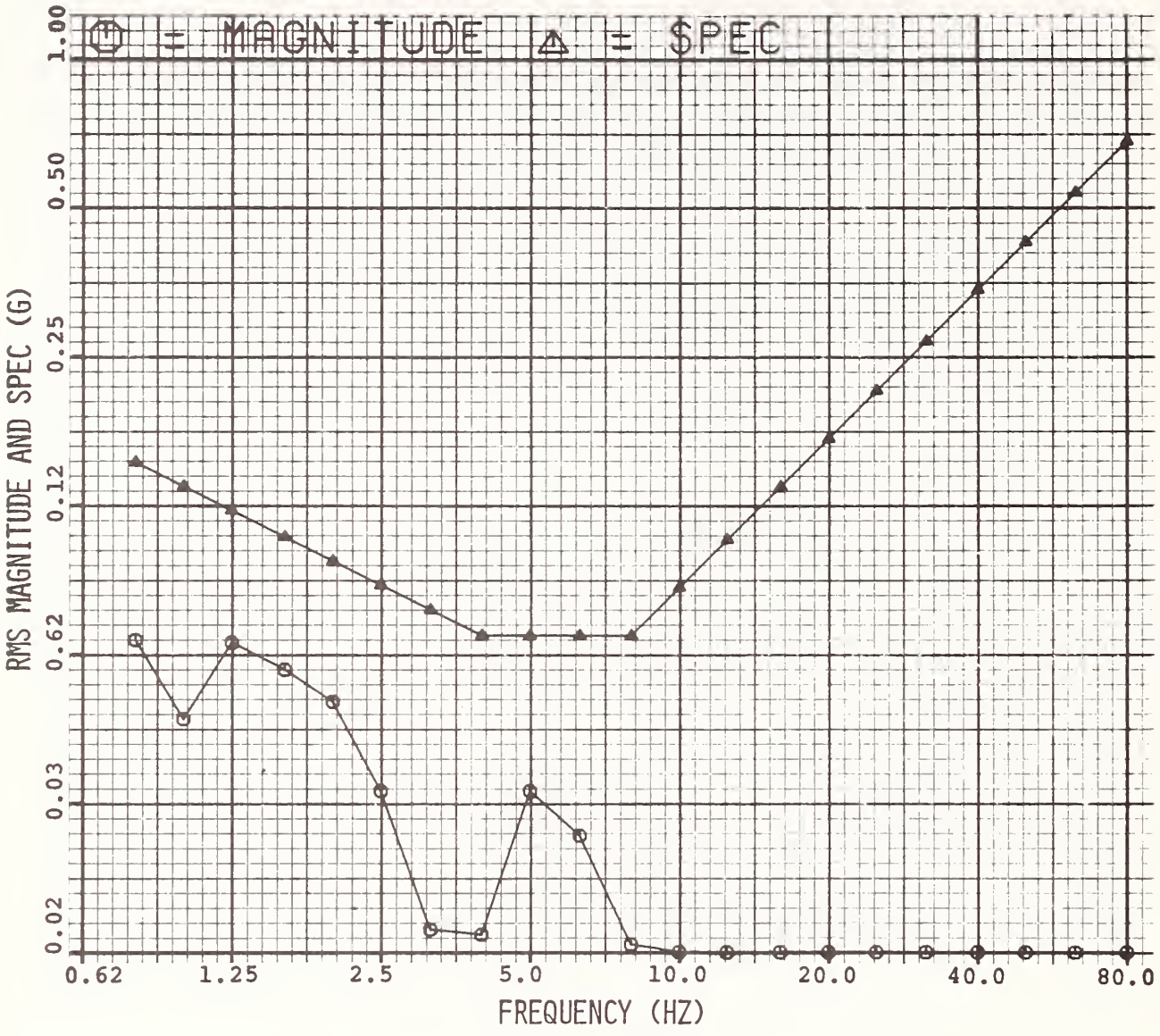


Figure C-31. ASL Wheelchair Passenger Vertical Acceleration, Heavy Load, 40 mph.

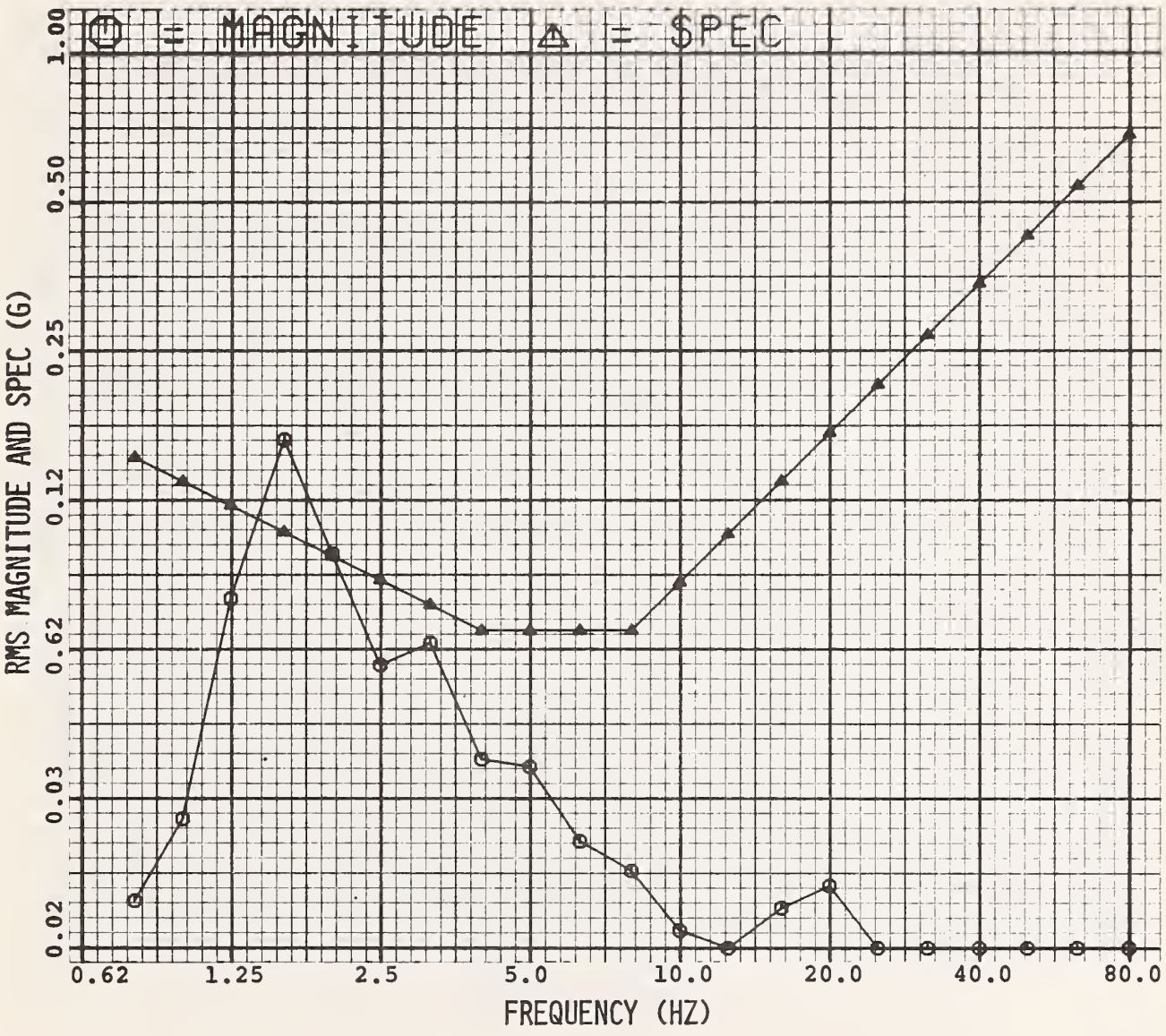


Figure C-32. ASL Rear Seat Passenger Vertical Acceleration, Heavy Load, 5 mph.

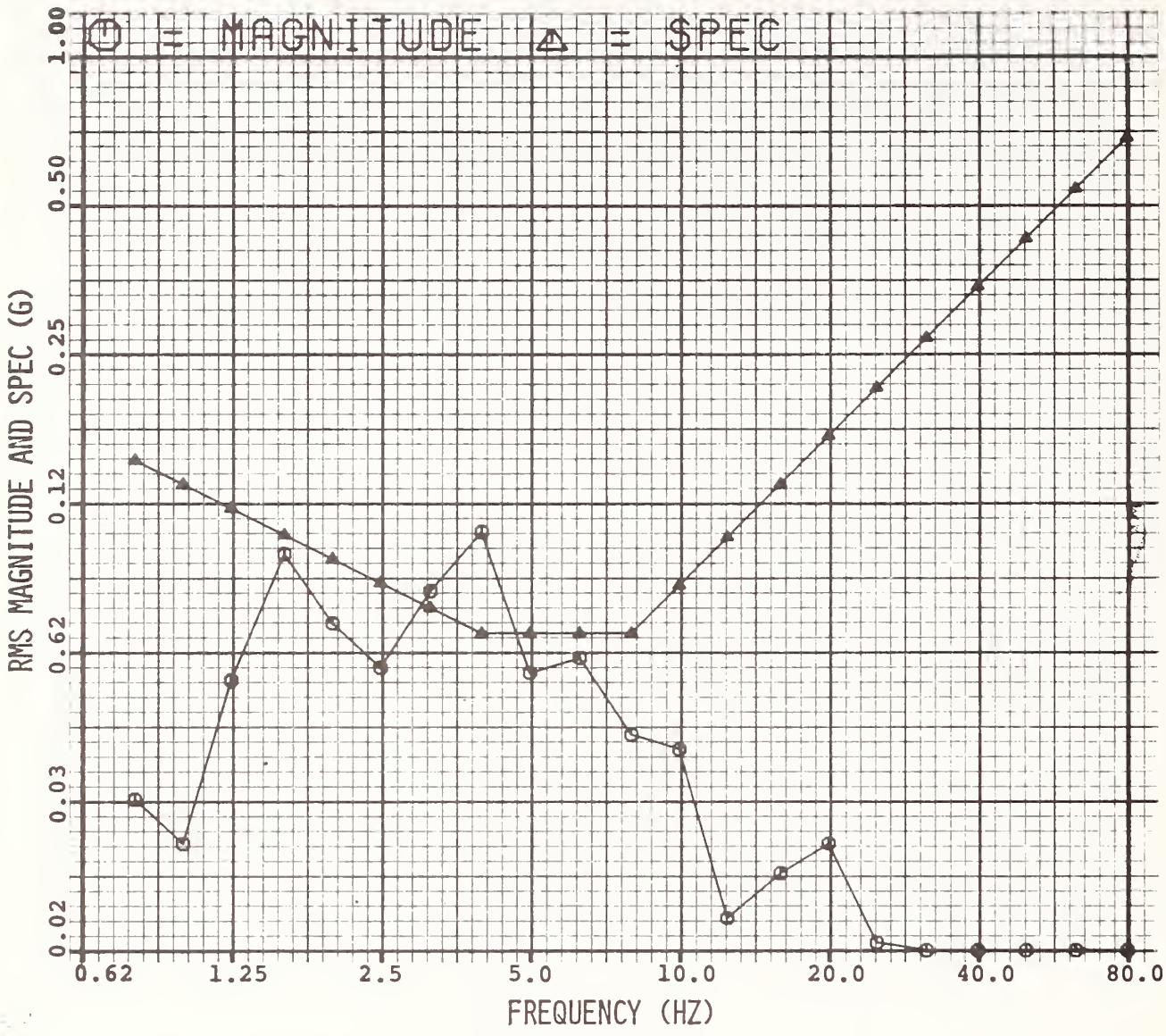


Figure C-33. ASL Rear Seat Passenger Vertical Acceleration, Heavy Load, 10 mph.

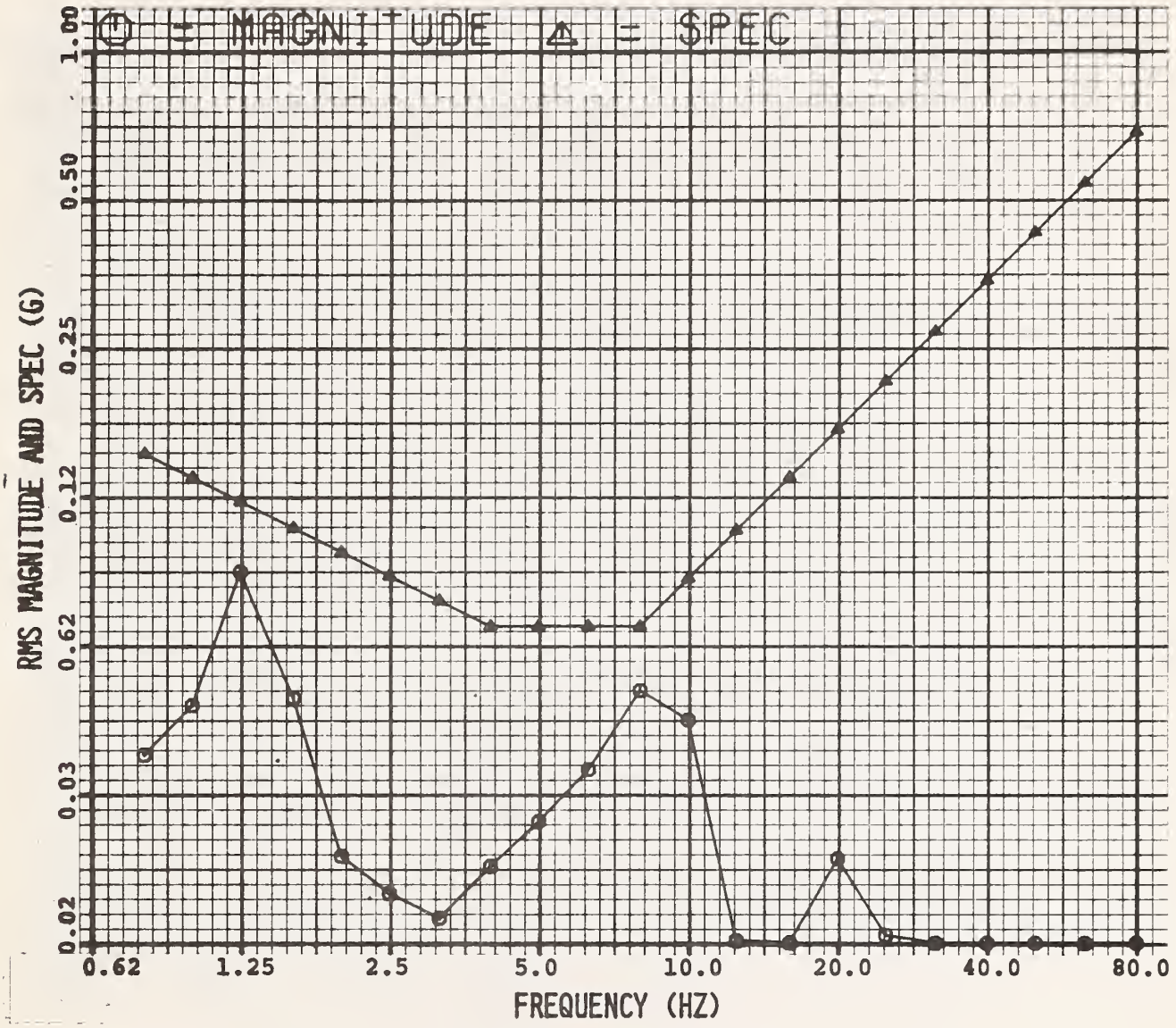


Figure C-34. ASL Rear Seat Passenger Vertical Acceleration, Heavy Load, 20 mph.

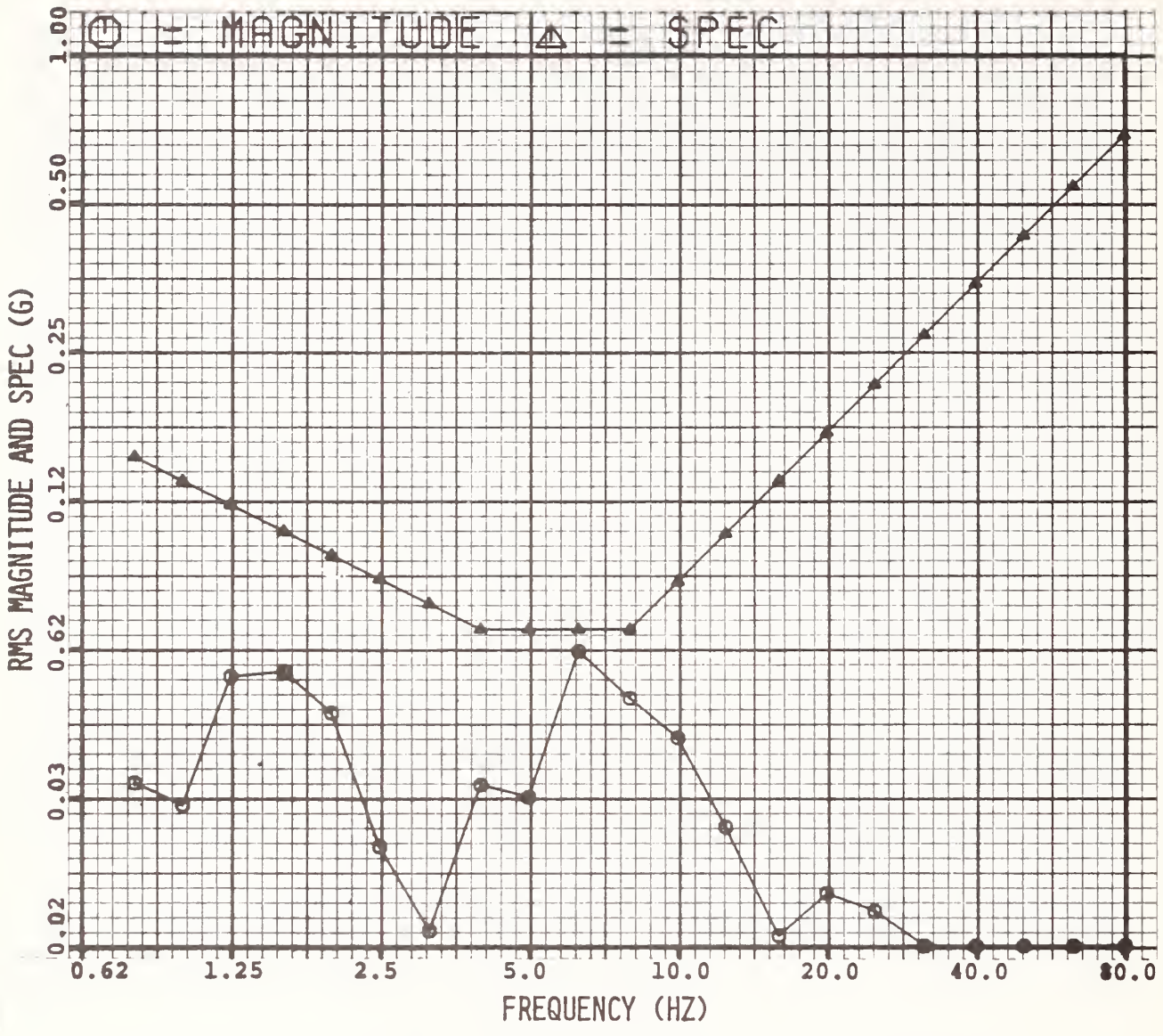


Figure C-35. ASL Rear Seat Passenger Vertical Acceleration, Heavy Load, 30 mph.

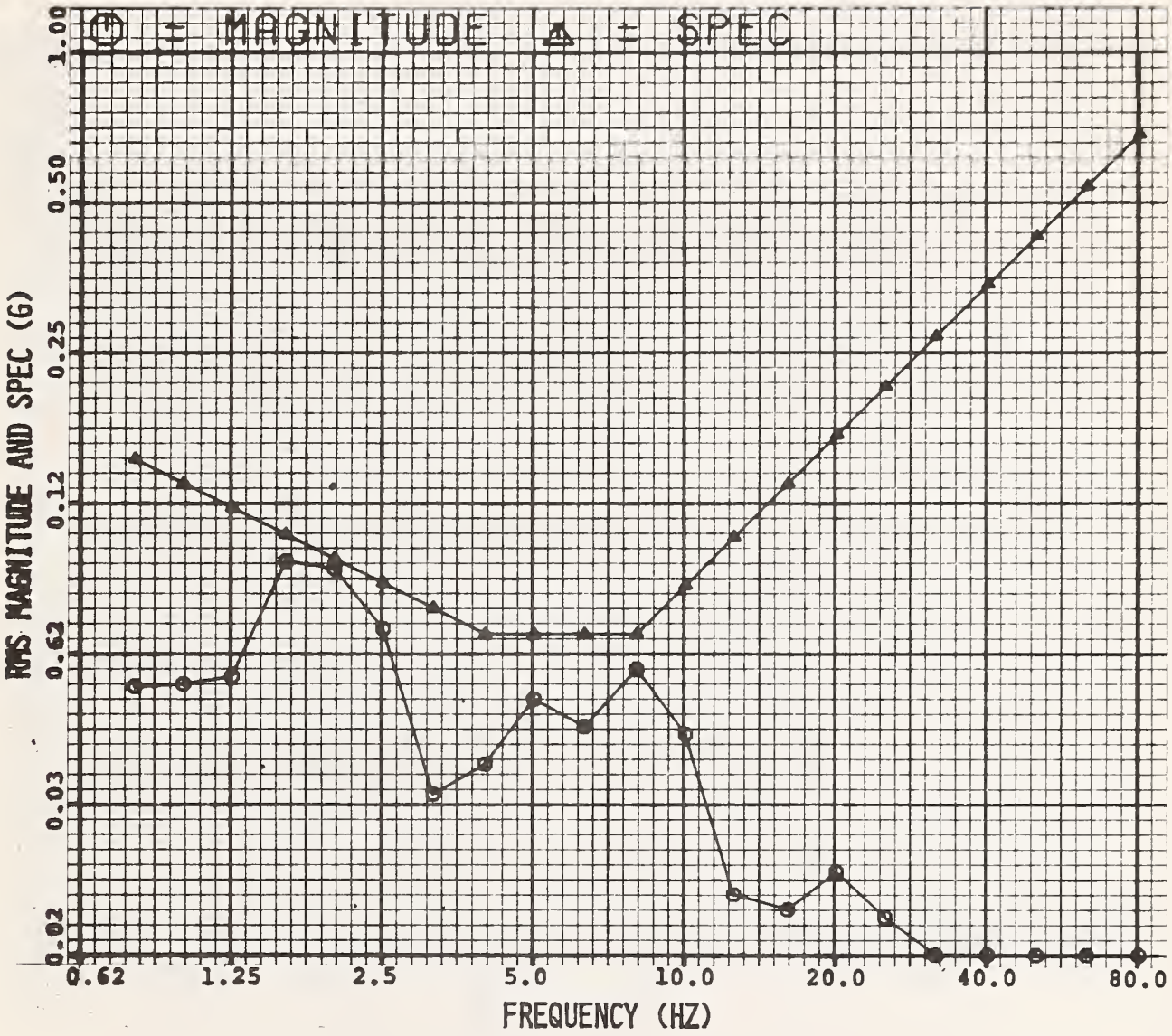


Figure C-36. ASL Rear Seat Passenger Vertical Acceleration, Heavy Load, 40 mph.

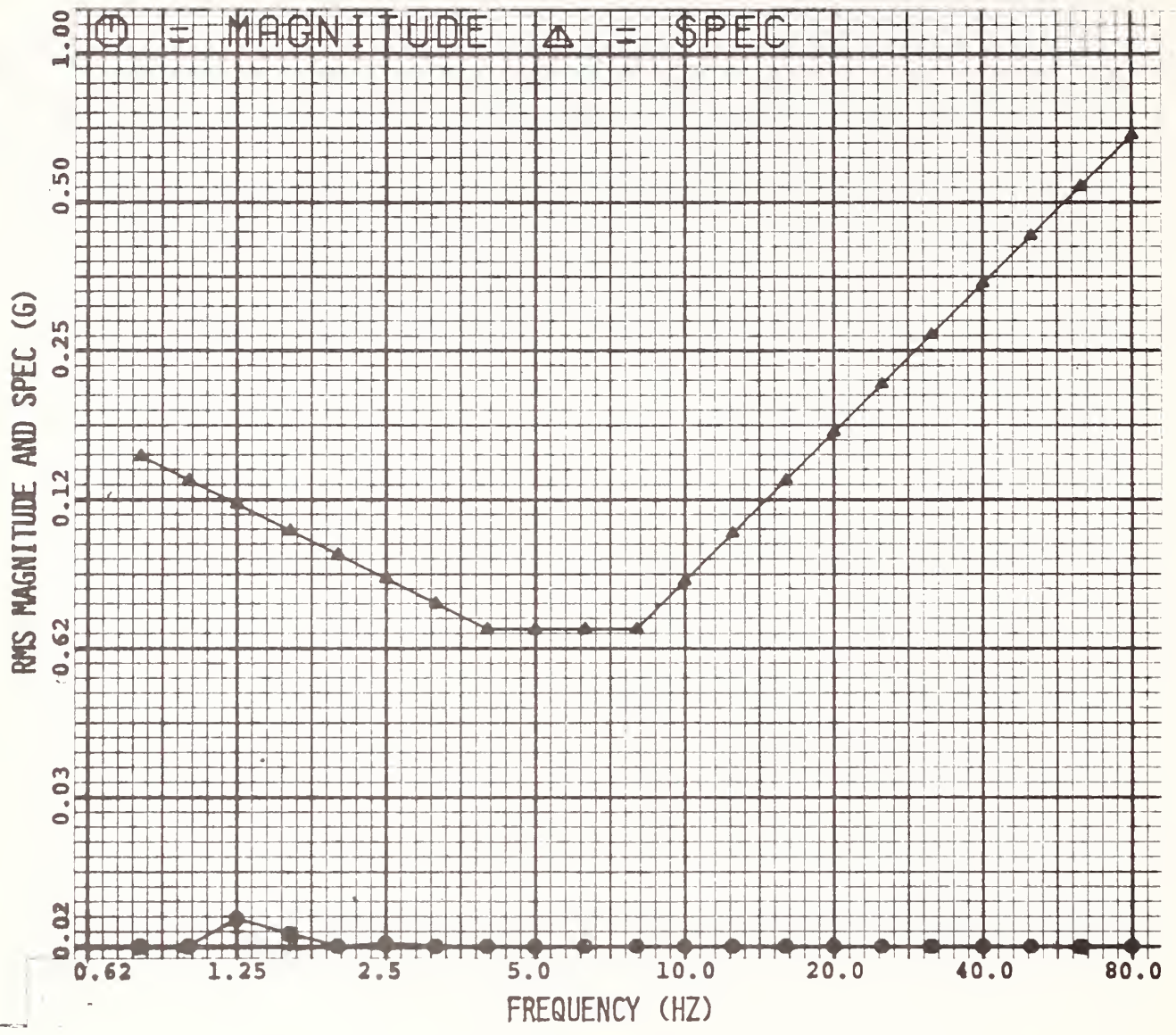


Figure C-37. ASL Wheelchair Passenger Vertical Acceleration, Urban Driving Course.

APPENDIX D

DUTCHER OCCUPANT VERTICAL ACCELERATIONS VERSUS FREQUENCY

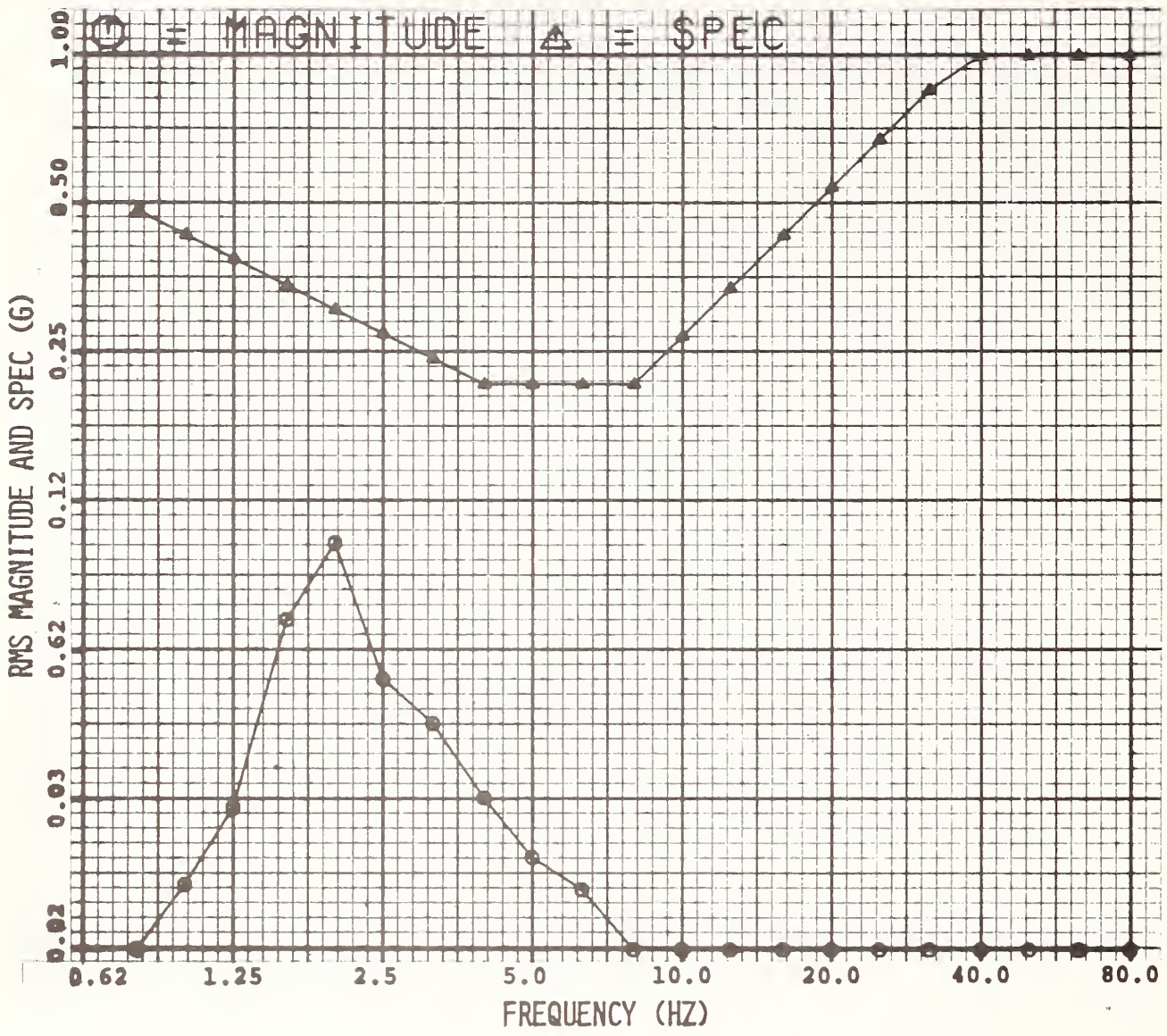


Figure D-1. Dutcher Driver Vertical Acceleration, Light Load (Wheelchair Passenger), 5 mph.

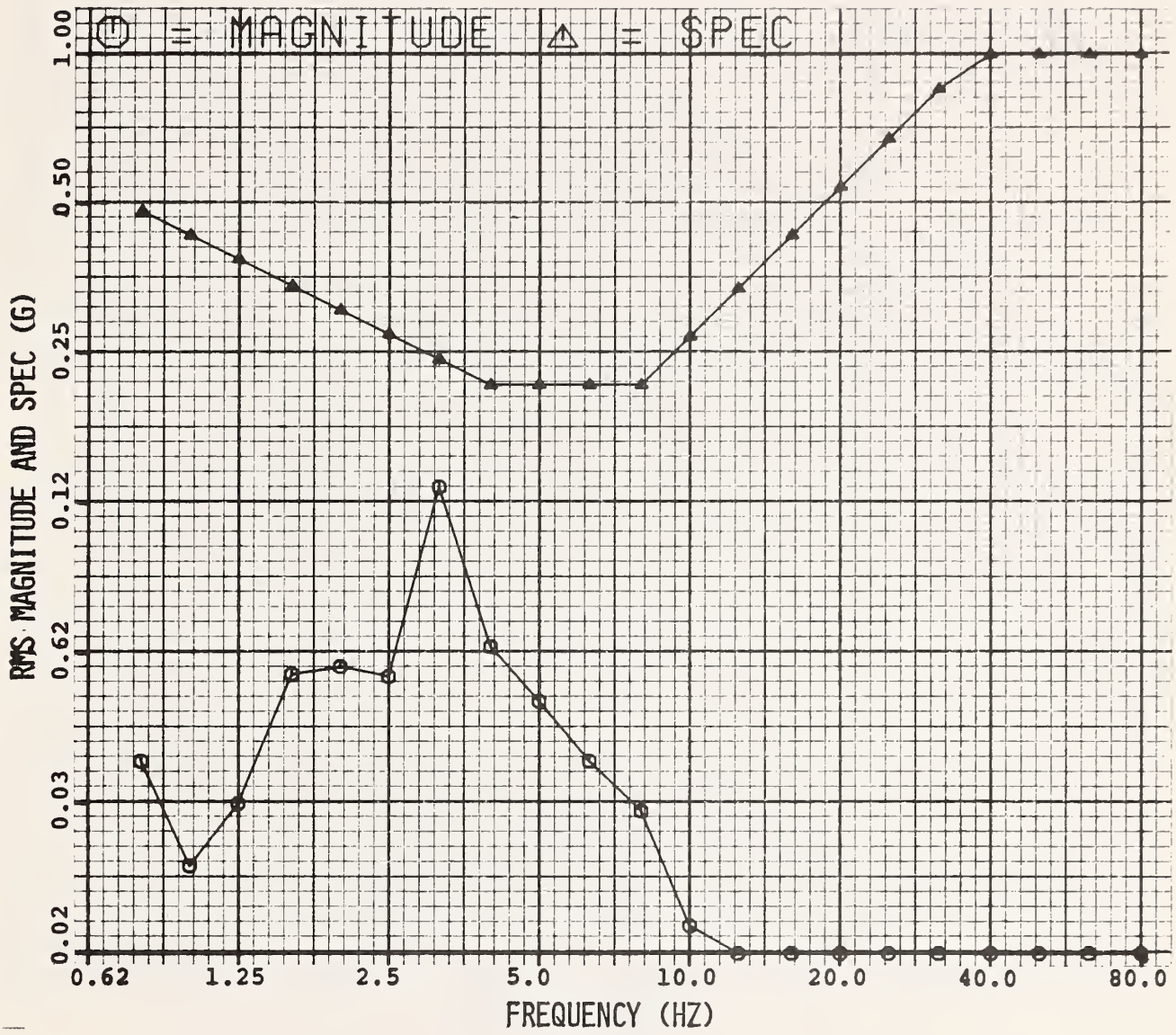


Figure D-2. Dutcher Driver Vertical Acceleration, Light Load, (Wheelchair Passenger), 10 mph.

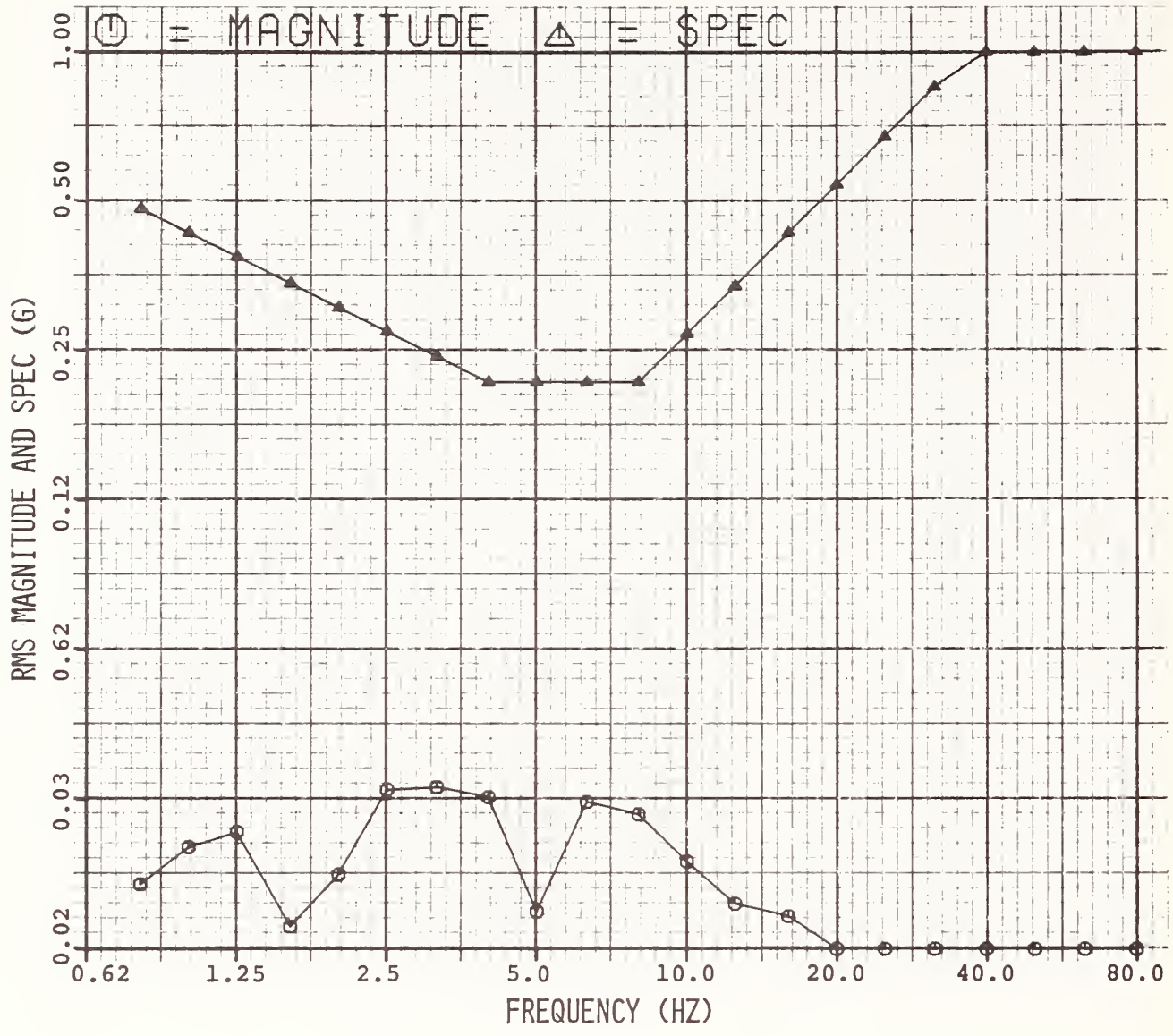


Figure D-3. Dutcher Driver Vertical Acceleration, Light Load (Wheelchair Passenger), 20 mph.

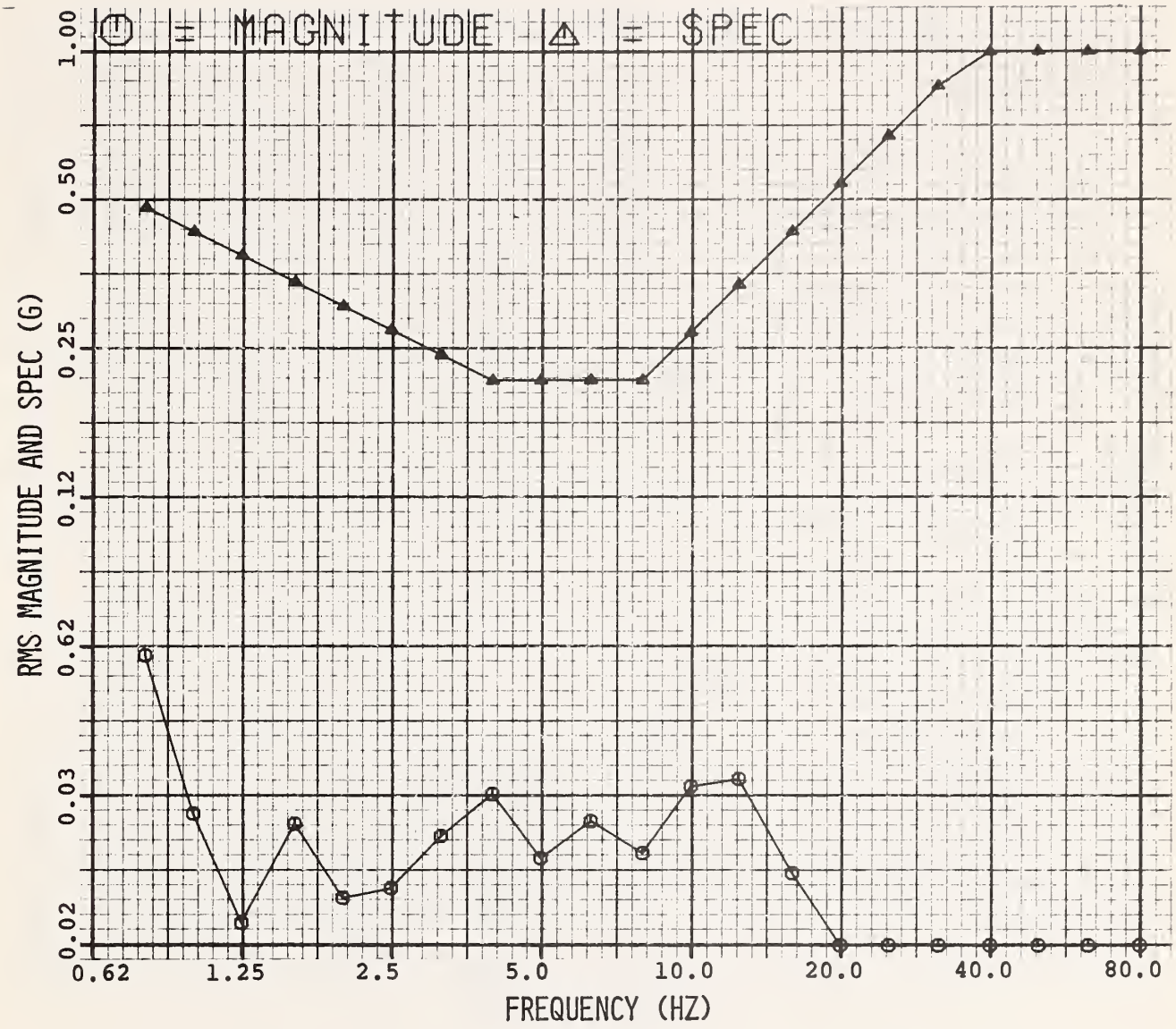


Figure D-4. Dutcher Driver Vertical Acceleration, Light Load, (Wheelchair Passenger), 30 mph.

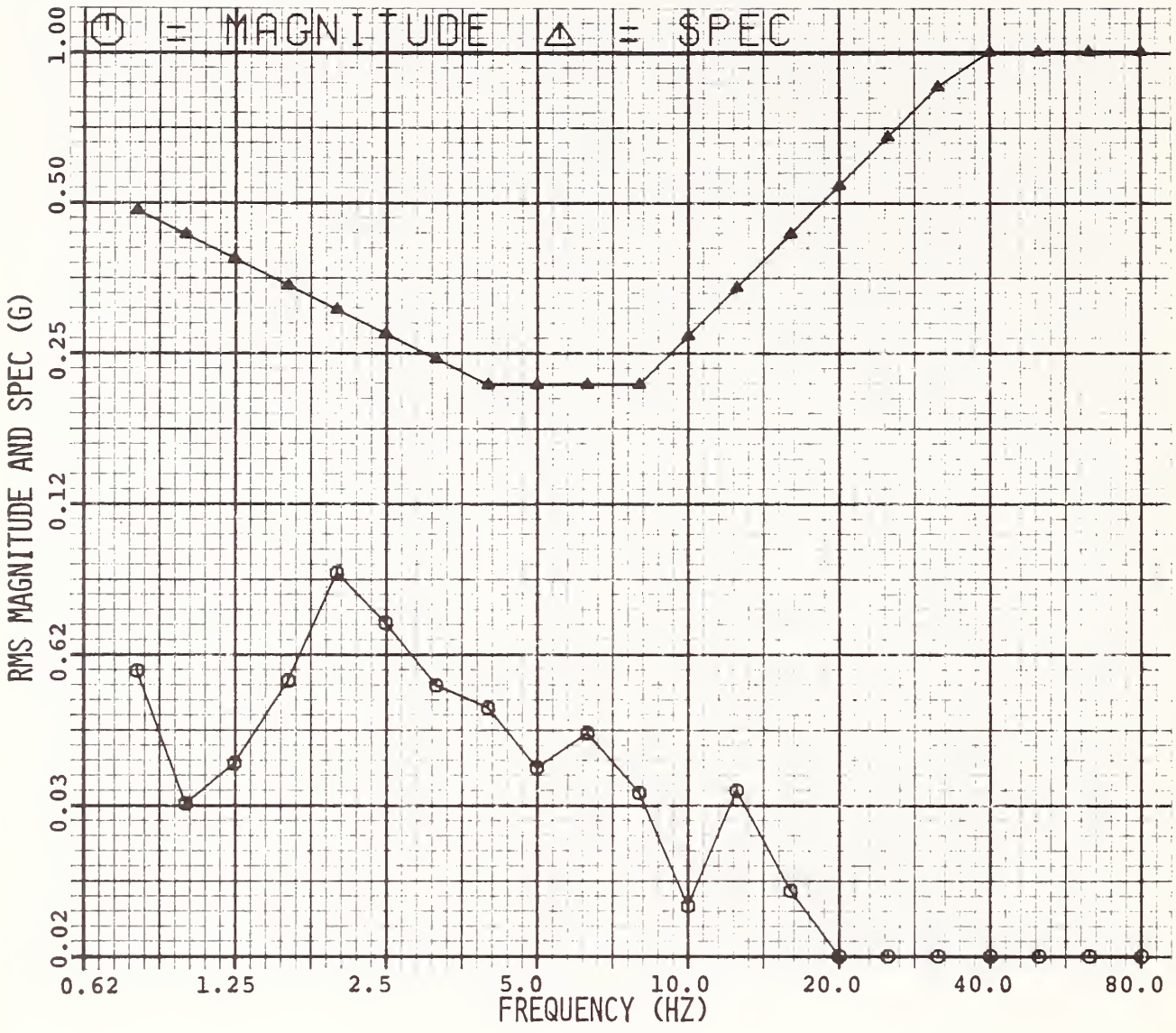


Figure D-5. Dutcher Driver Vertical Acceleration, Light Load (Wheelchair Passenger), 40 mph.

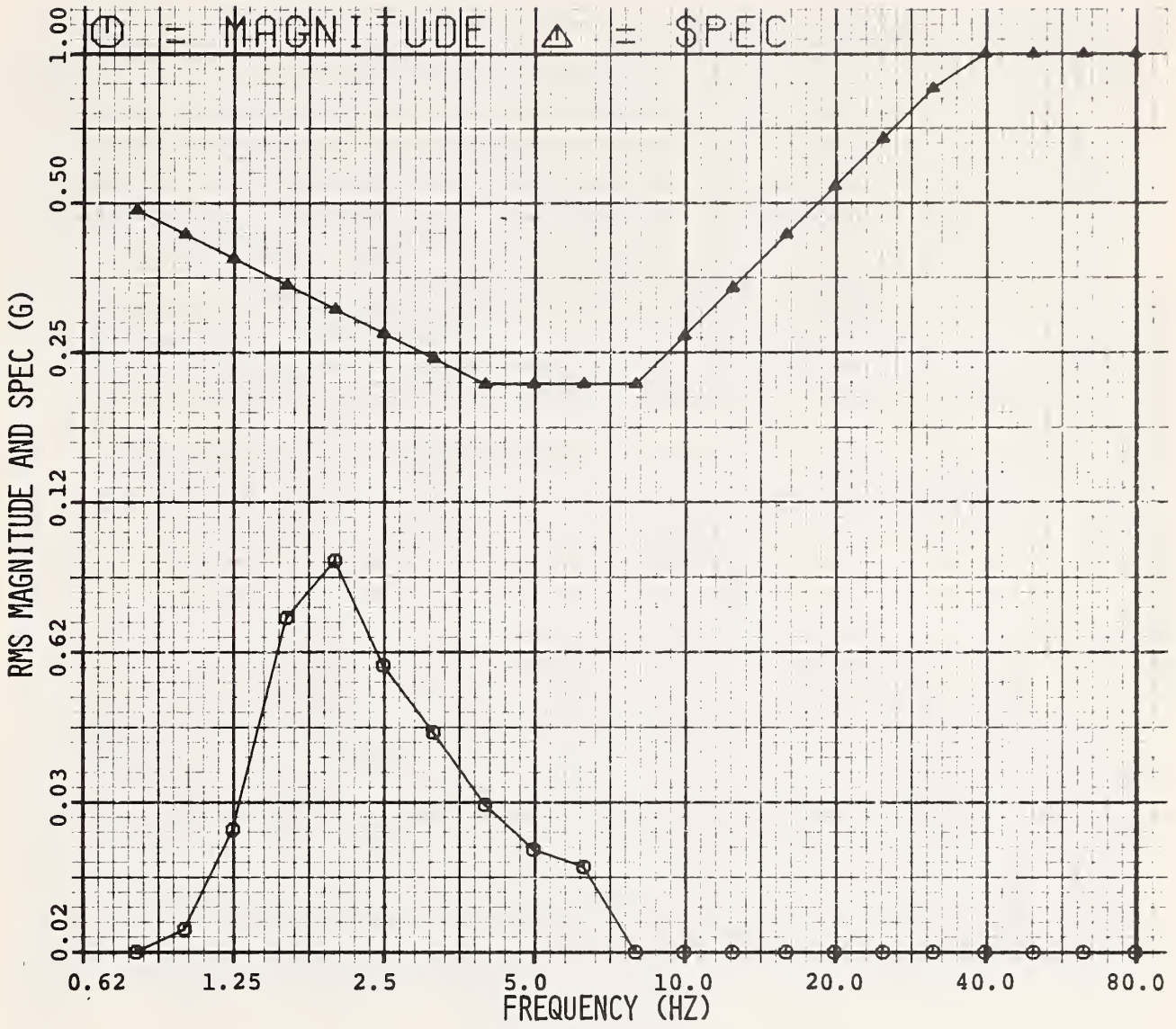


Figure D-6. Dutcher Driver Vertical Acceleration, Light Load (Rear Seat Passenger), 5 mph.

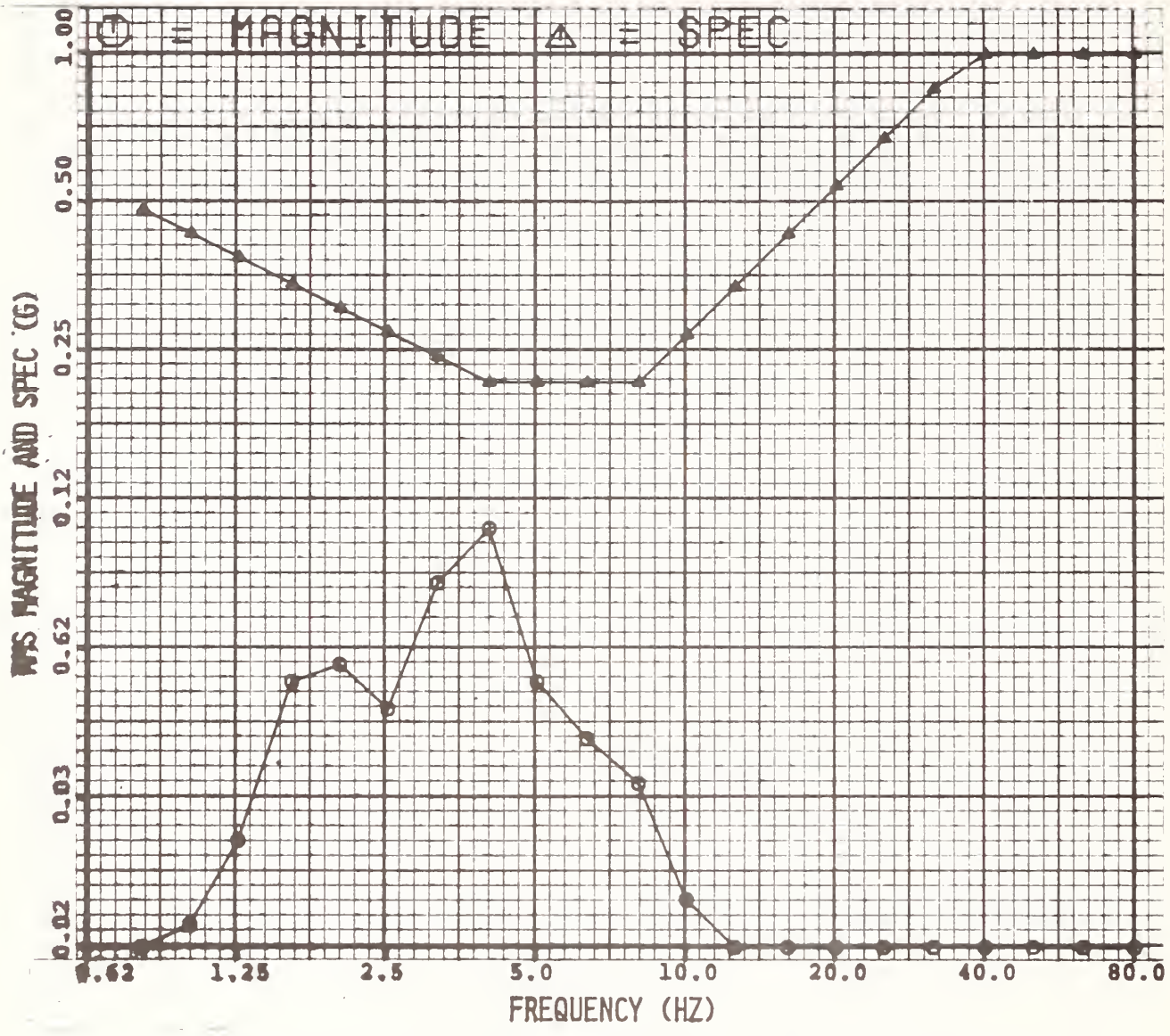


Figure D-7. Dutcher Driver Vertical Acceleration, Light Load (Rear Seat Passenger), 10 mph.

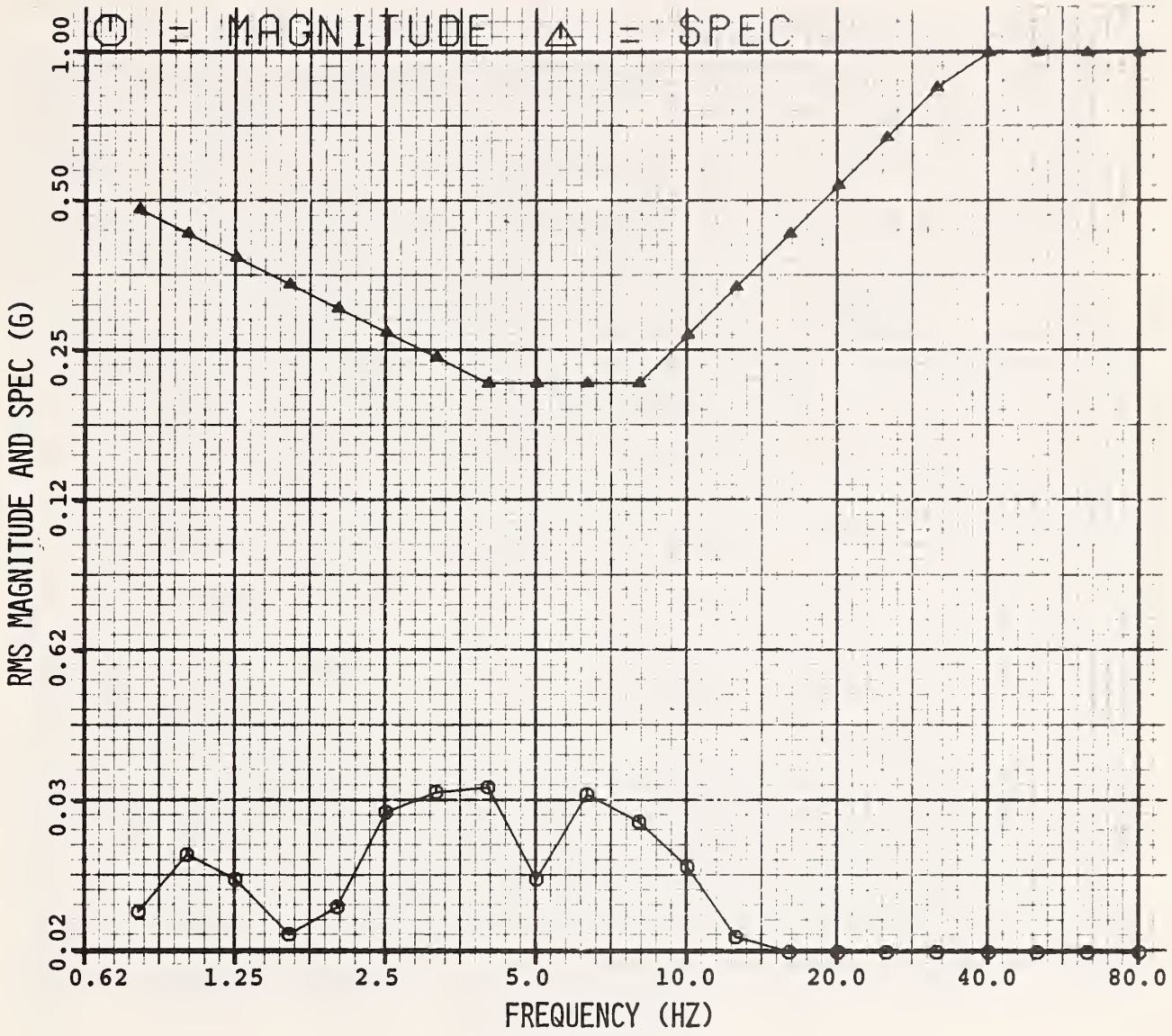


Figure D-8. Dutcher Driver Vertical Acceleration, Light Load (Rear Seat Passenger), 20 mph.

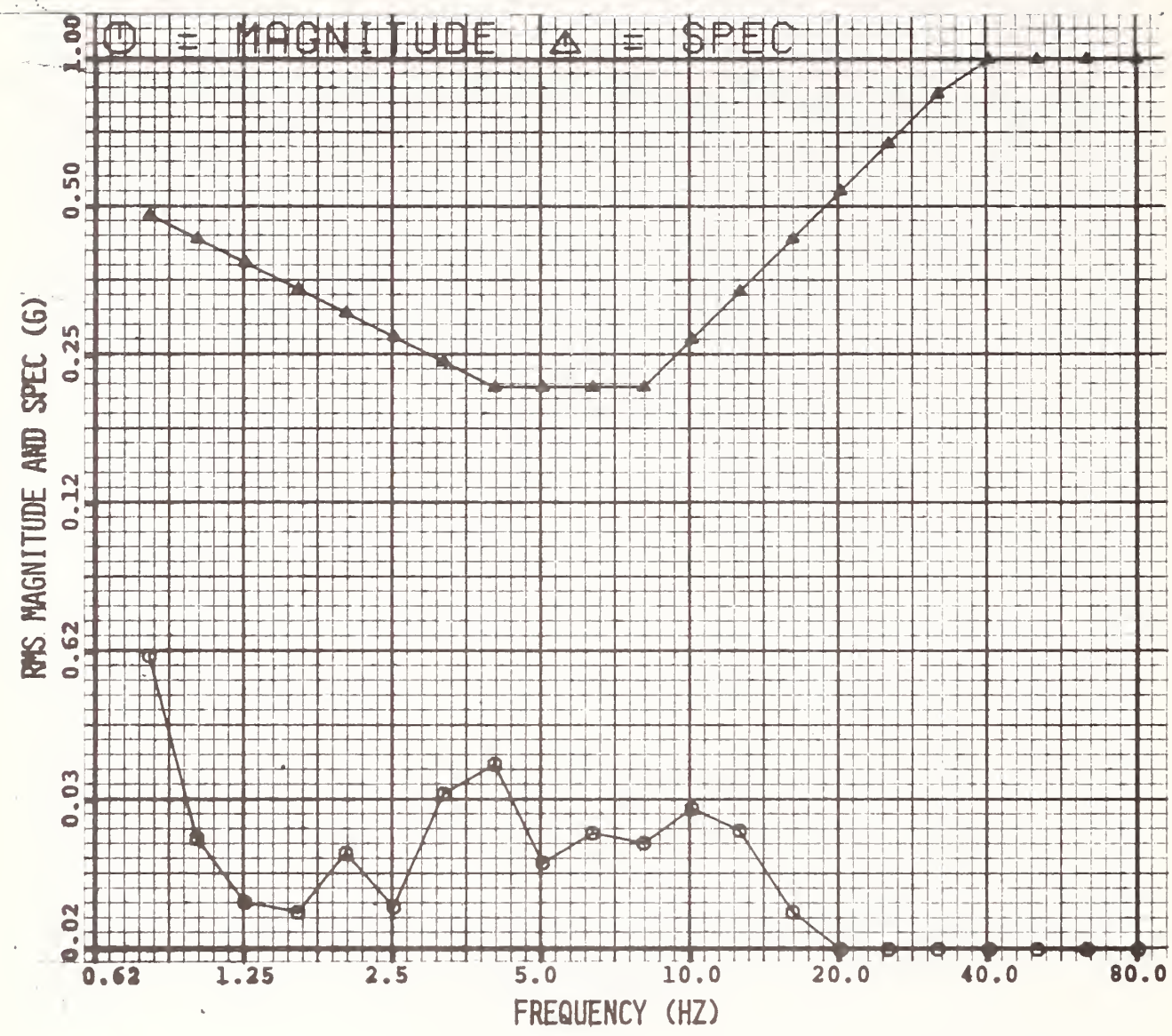


Figure D-9. Dutcher Driver Vertical Acceleration, Light Load (Rear Seat Passenger), 30 mph.

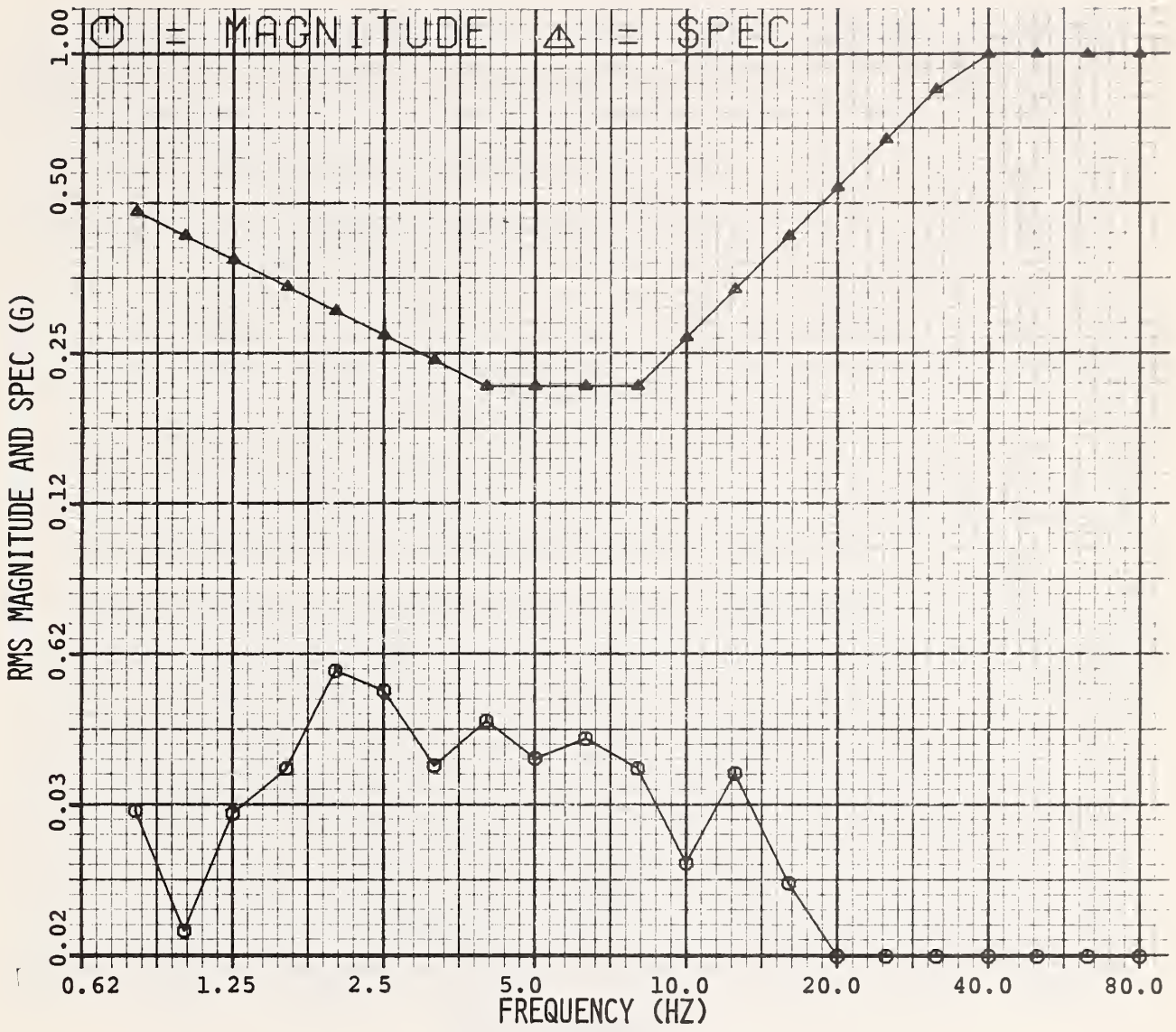


Figure D-10. Dutcher Driver Vertical Acceleration, Light Load (Rear Seat Passenger), 40 mph.

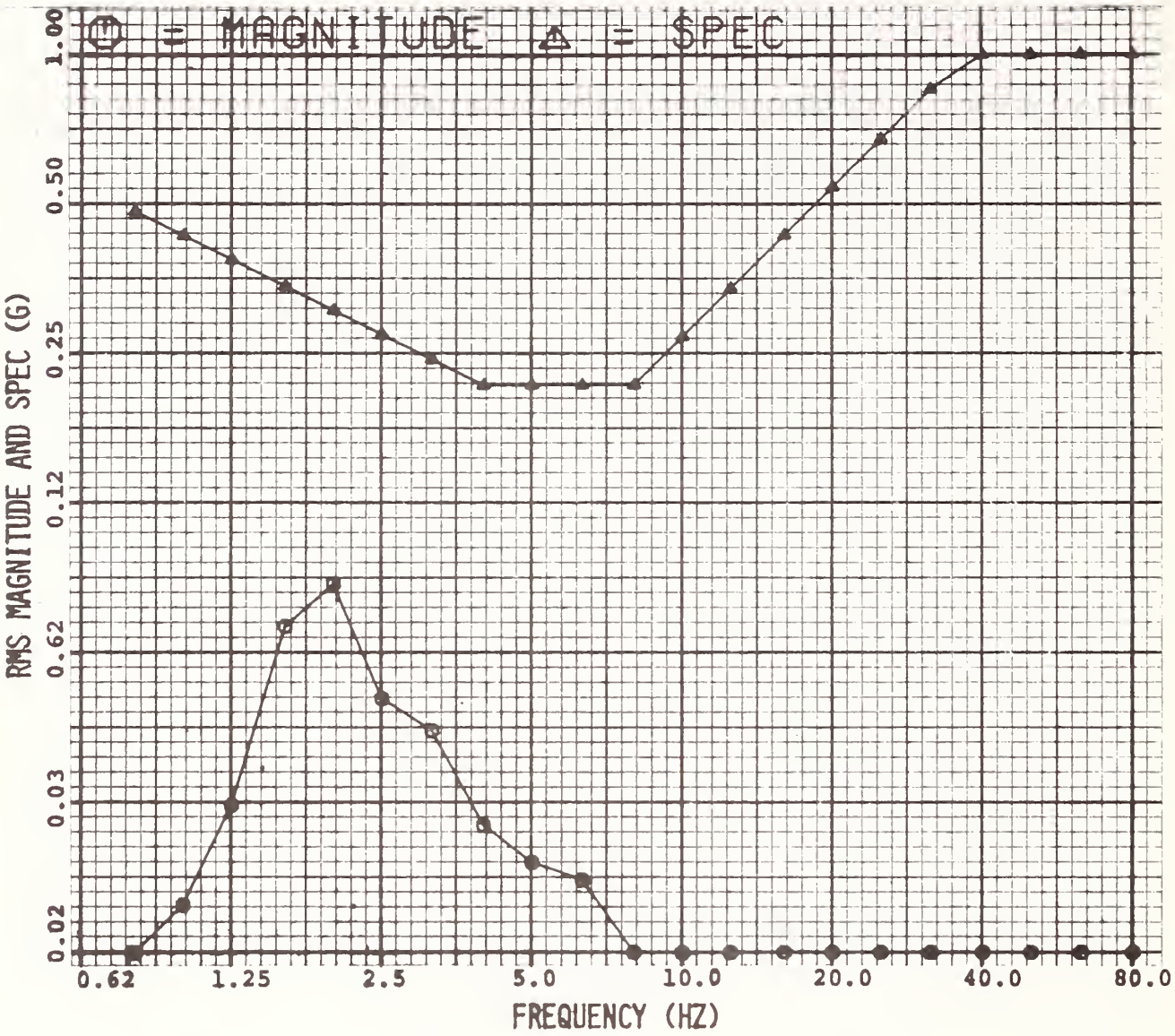


Figure D-11. Dutcher Driver Vertical Acceleration, Heavy Load, 5 mph.

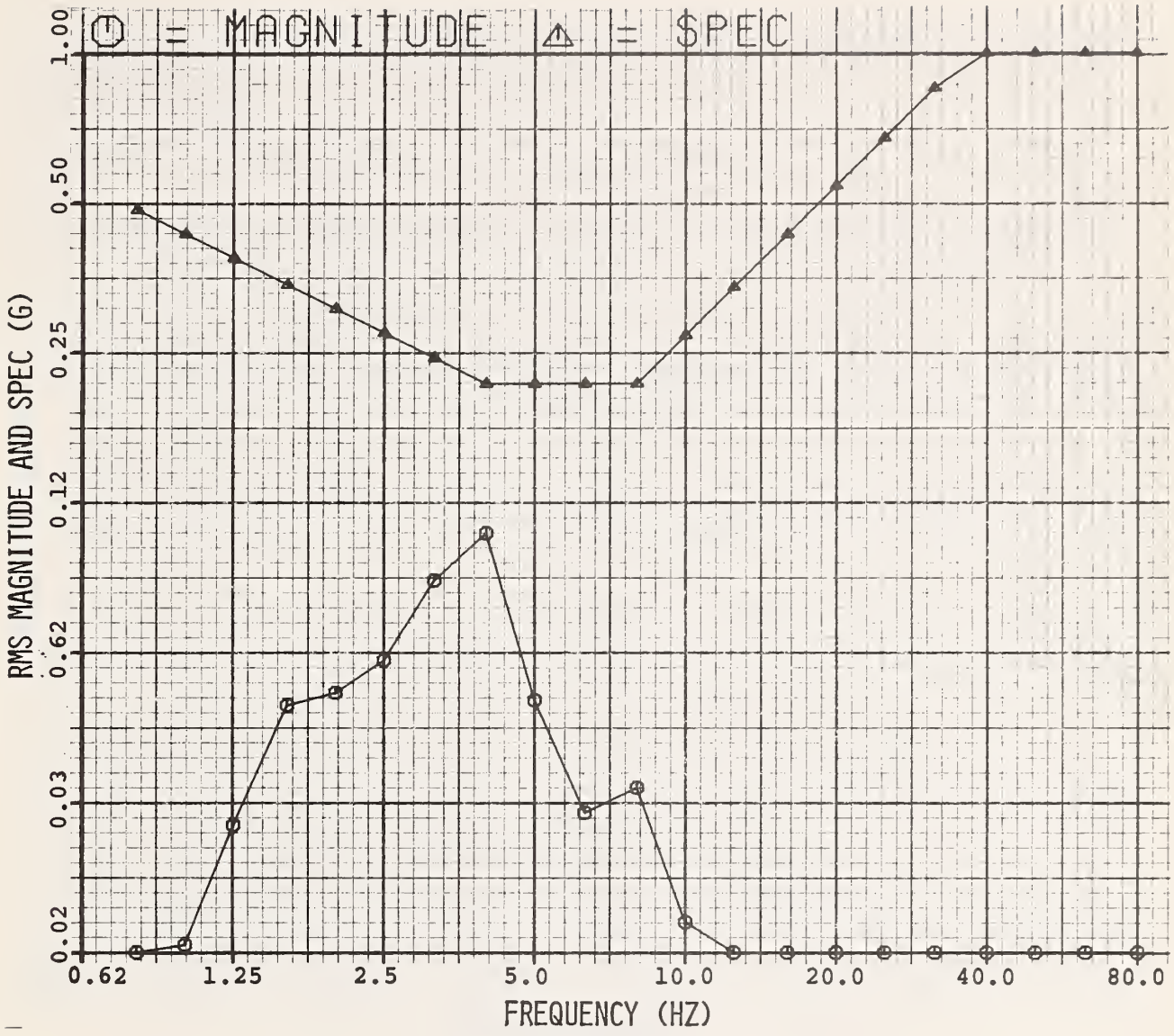


Figure D-12. Dutcher Driver Vertical Acceleration, Heavy Load, 10 mph.

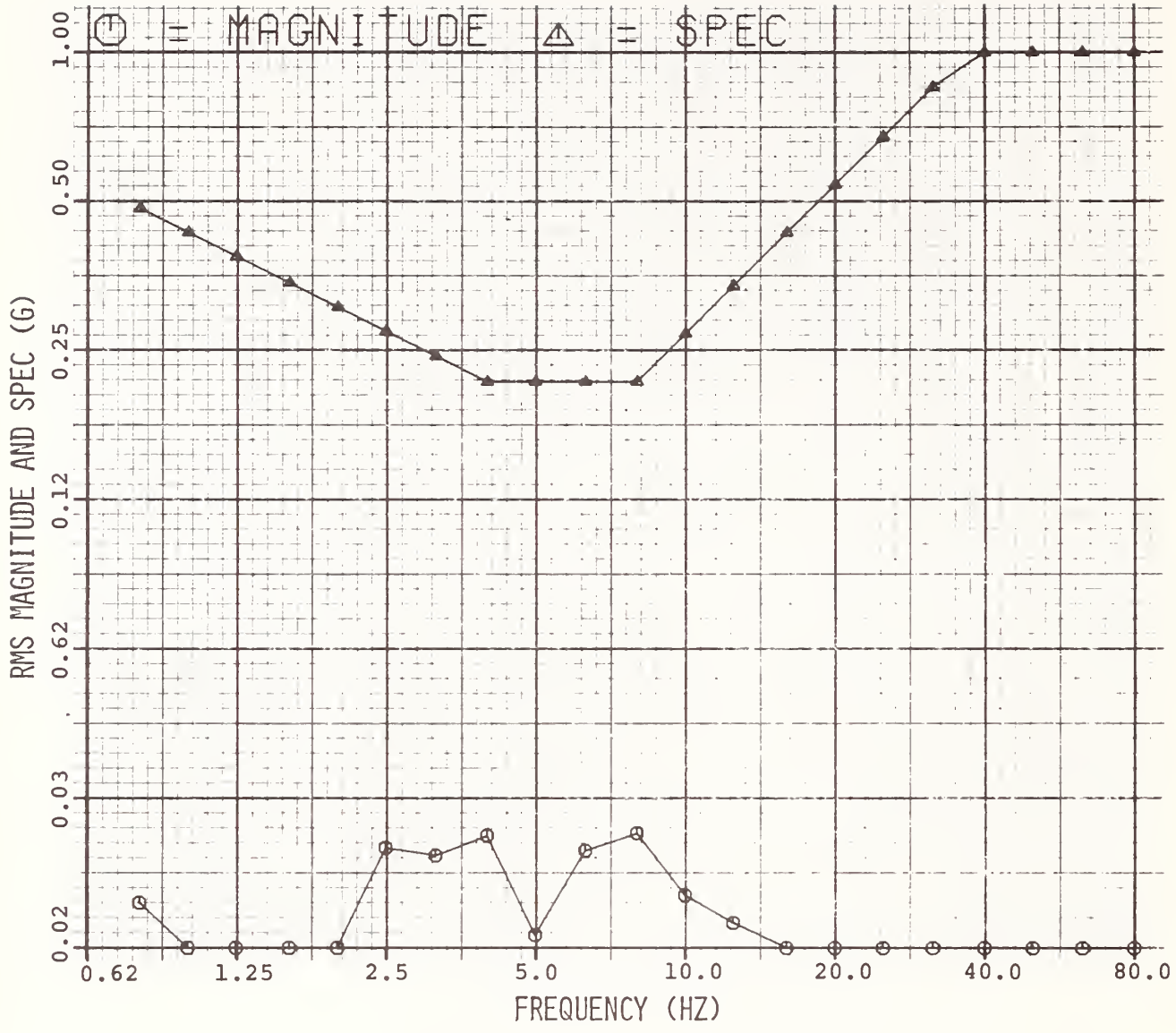


Figure D-13. Dutcher Driver Vertical Acceleration, Heavy Load, 20 mph.

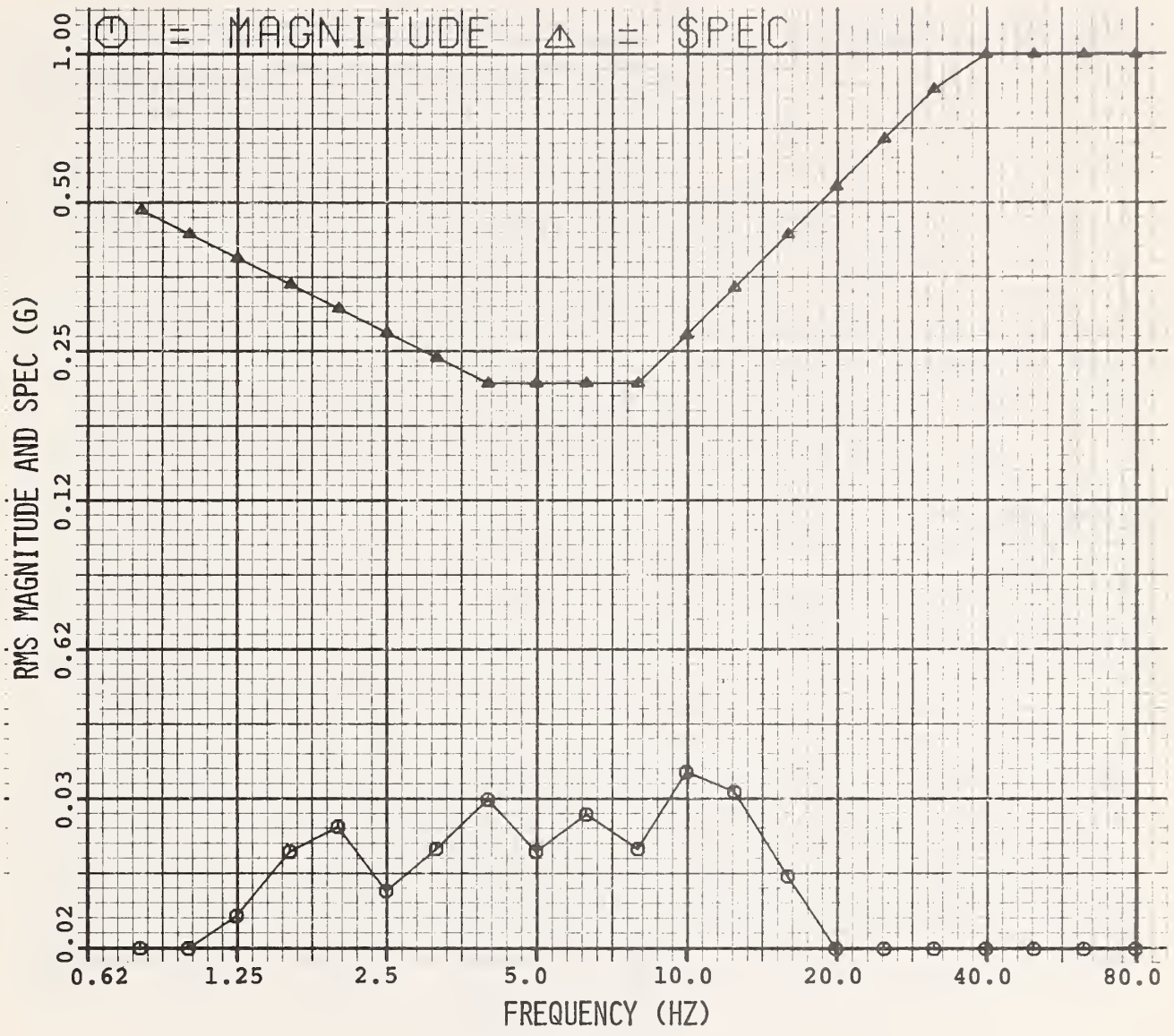


Figure D-14. Dutcher Driver Vertical Acceleration, Heavy Load, 30 mph.

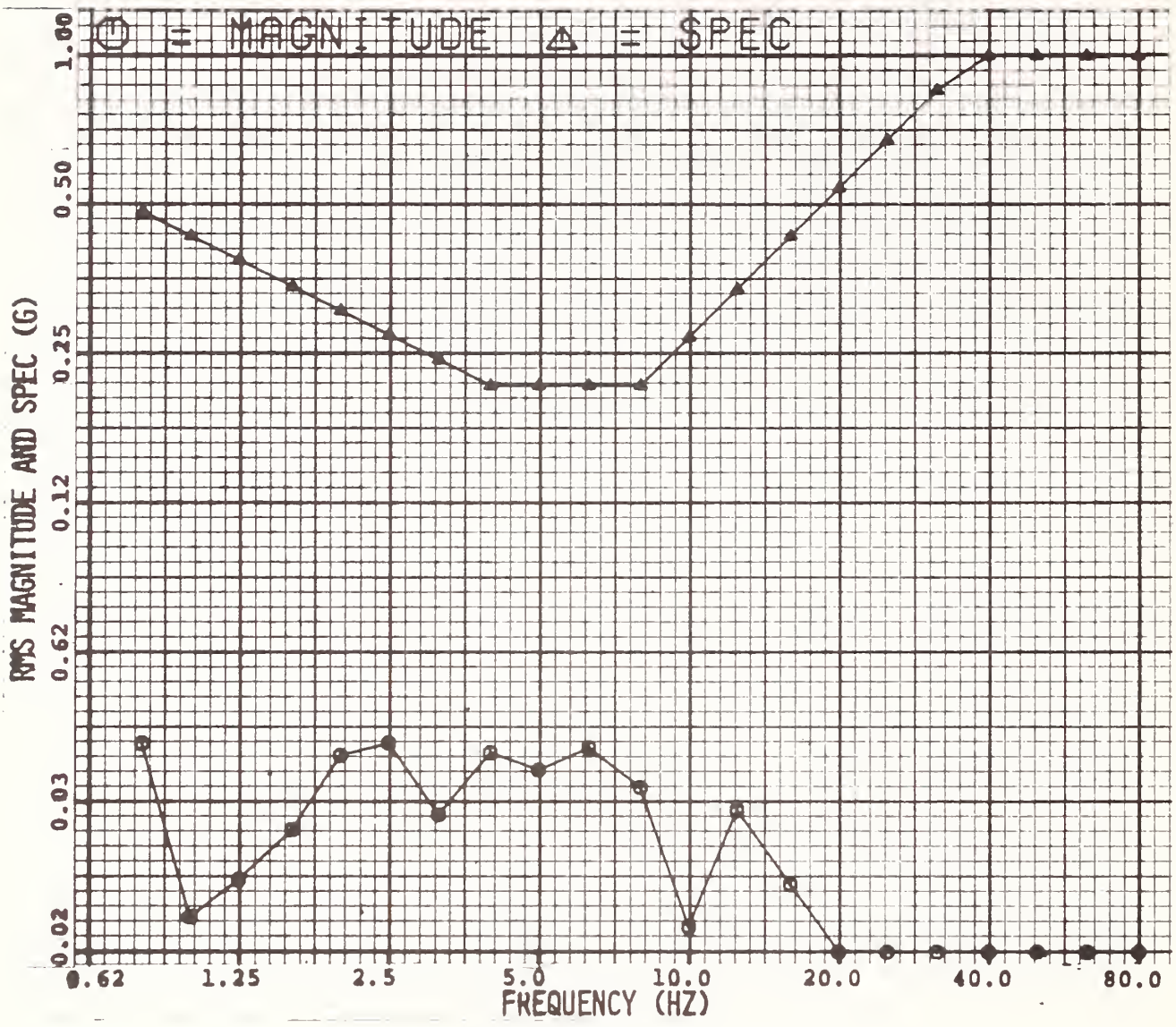


Figure D-15. Dutcher Driver Vertical Acceleration, Heavy Load, 40 mph.

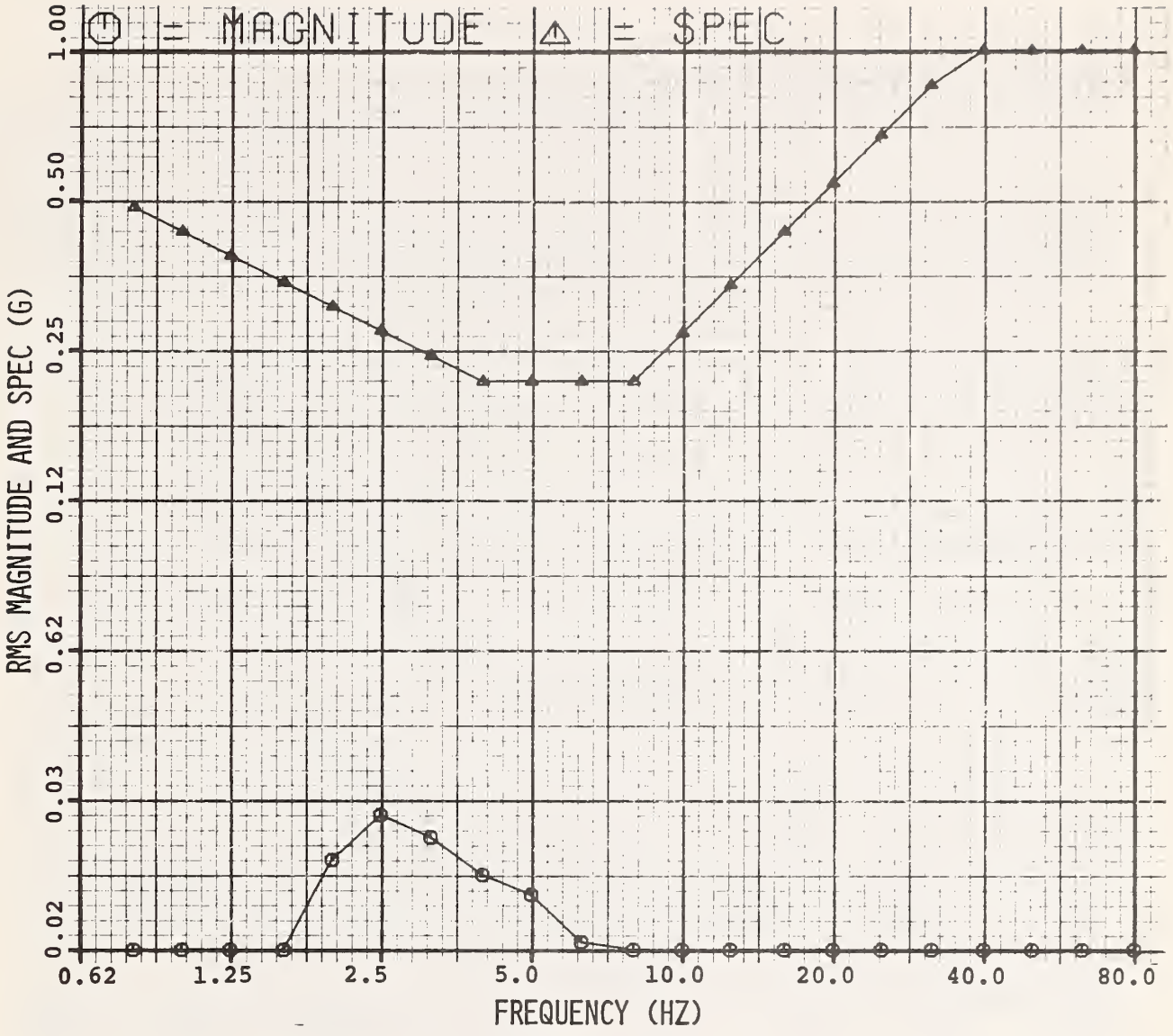


Figure D-16. Dutcher Driver Vertical Acceleration, Urban Driving Course.

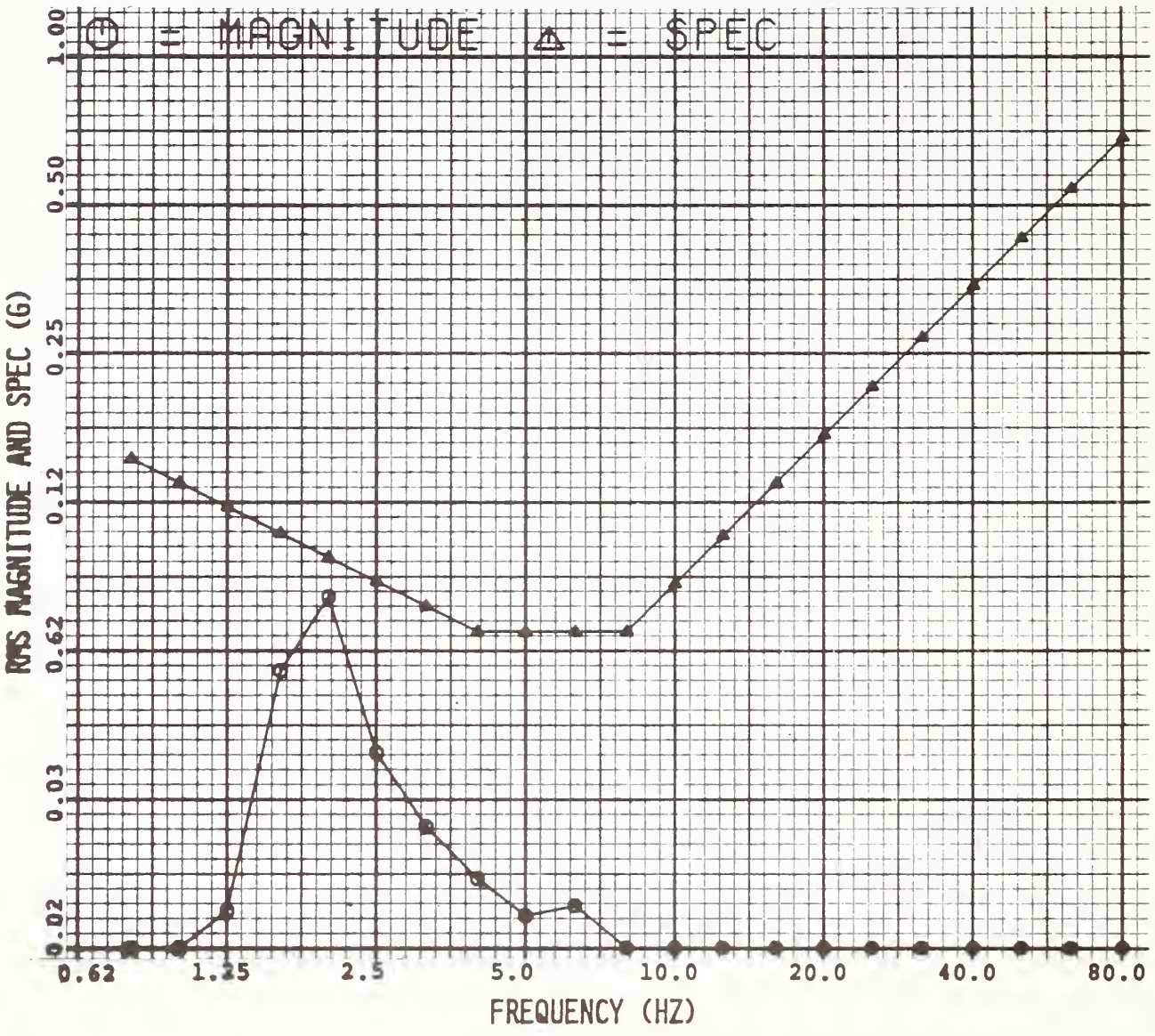


Figure D-17. Dutcher Wheelchair Passenger Vertical Acceleration, Light Load, 5 mph.

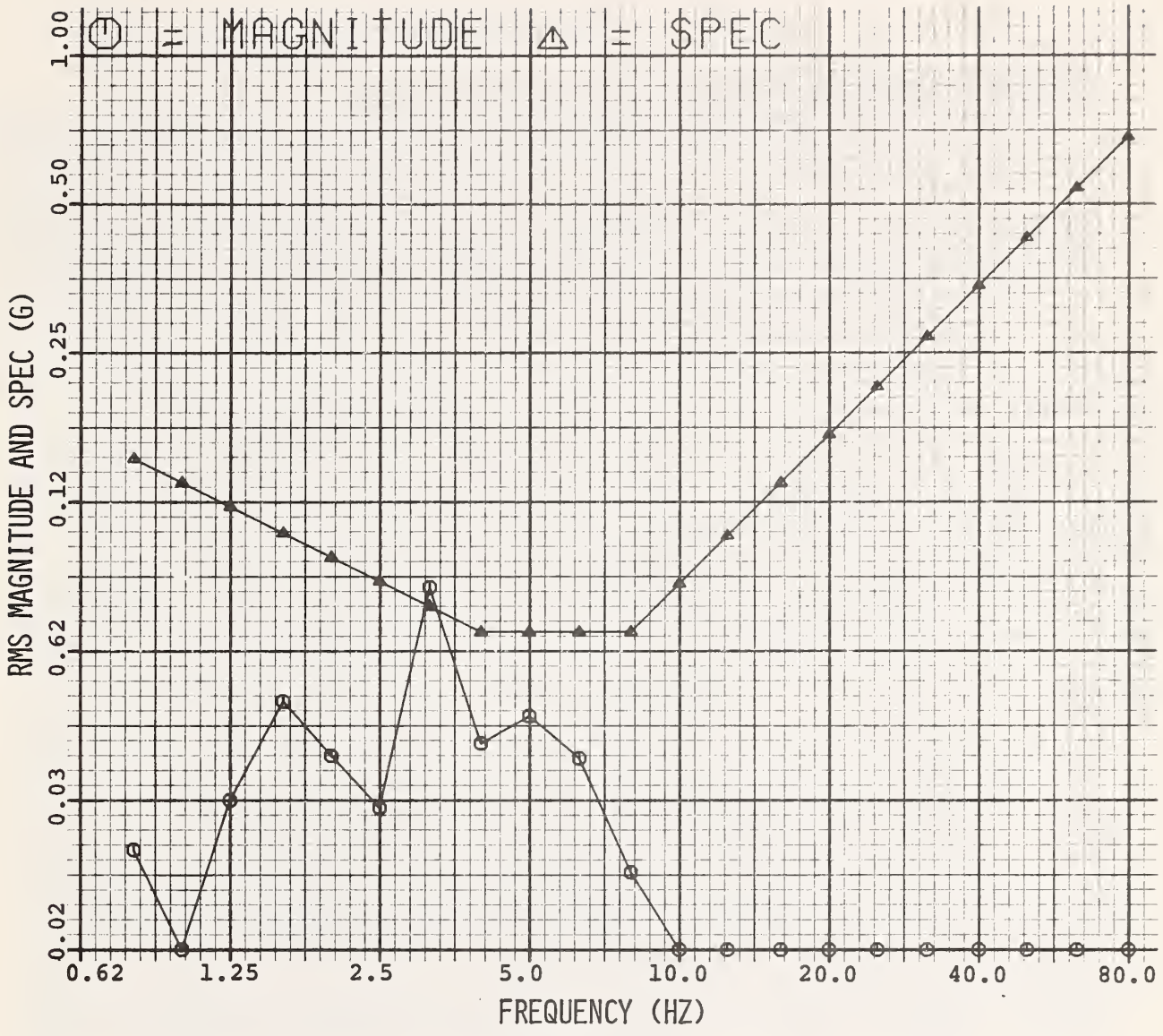


Figure D-18. Dutcher Wheelchair Passenger Vertical Acceleration, Light Load, 10 mph.

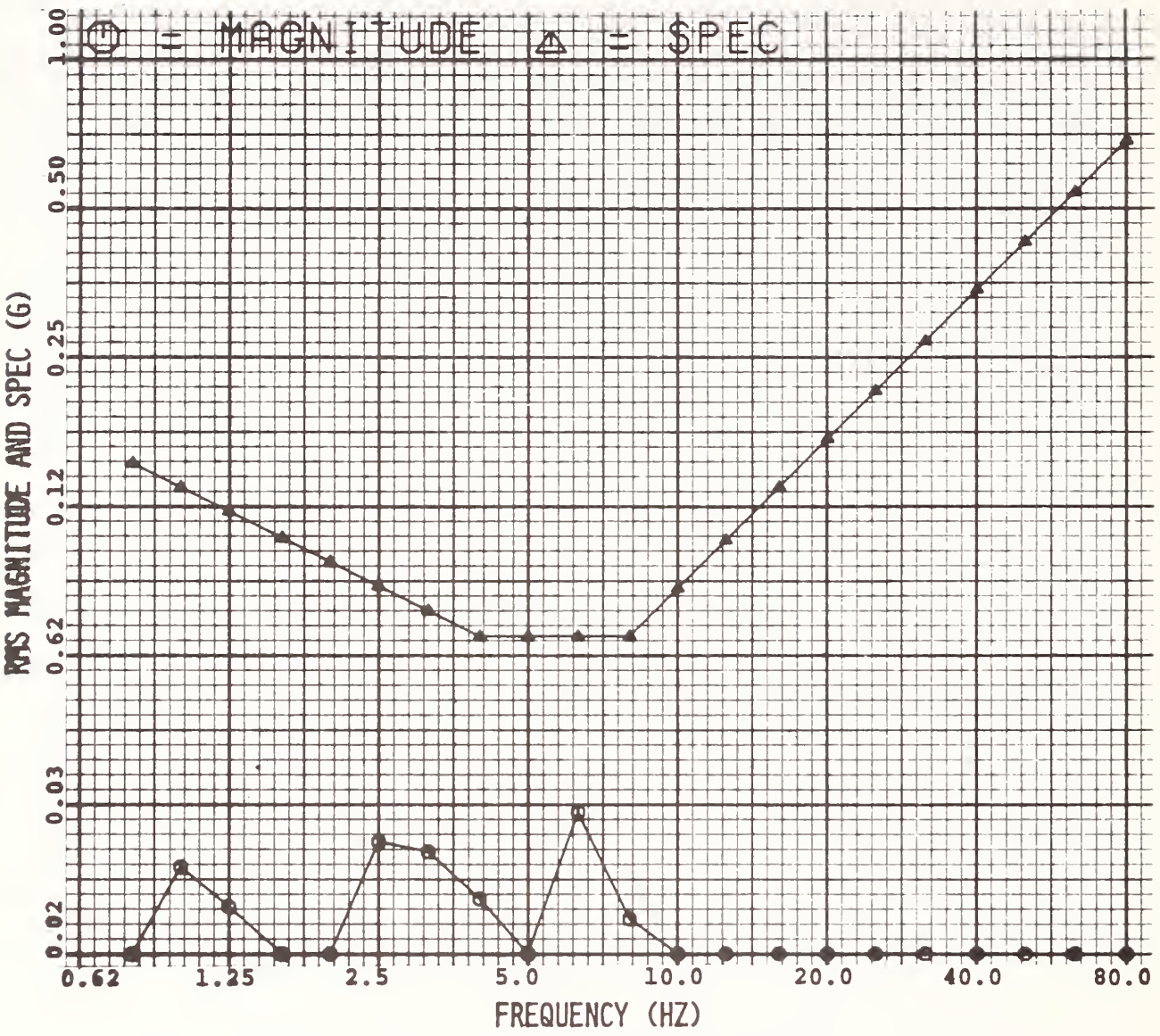


Figure D-19. Dutcher Wheelchair Passenger Vertical Acceleration, Light Load, 20 mph.

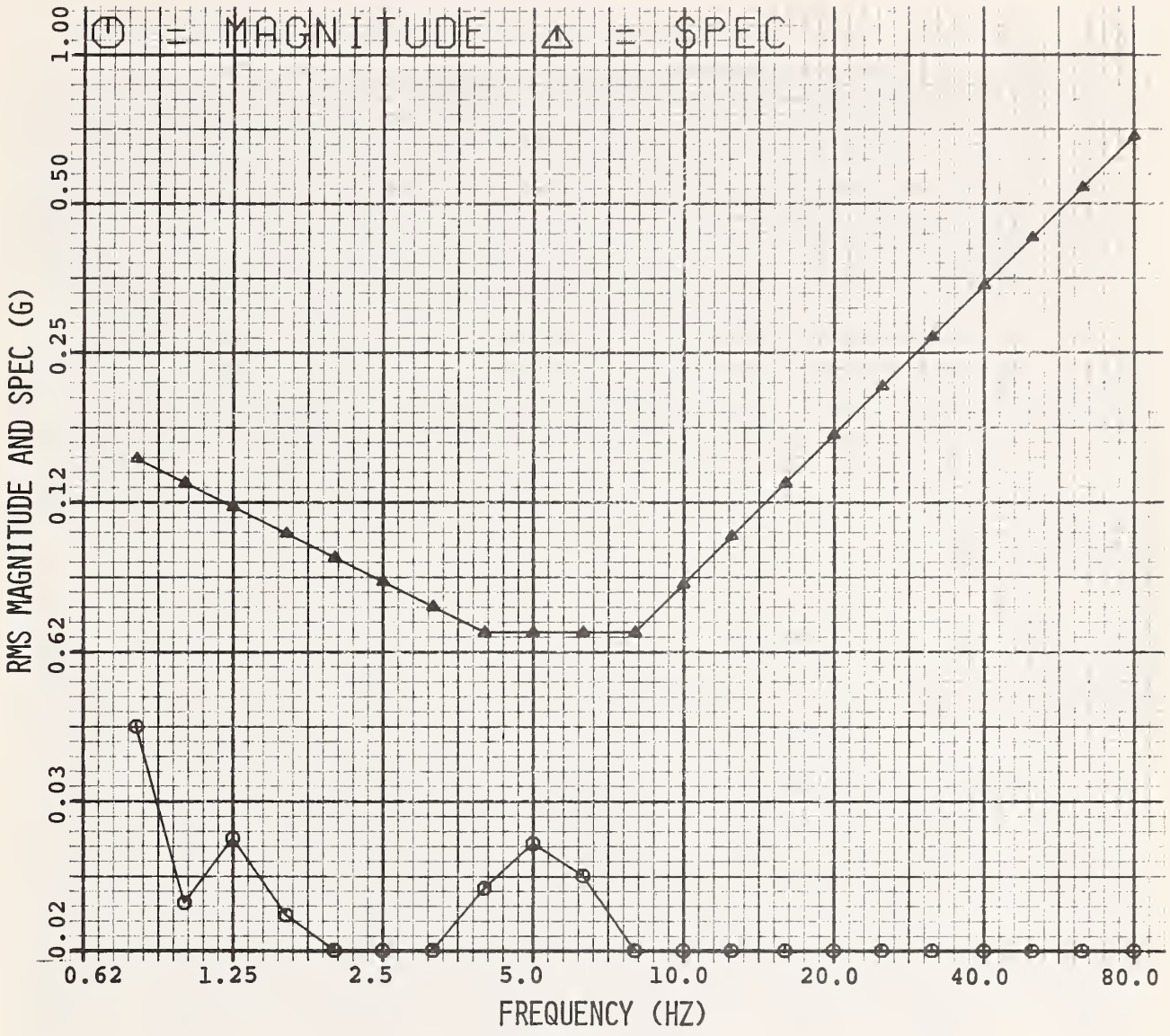


Figure D-20. Dutcher Wheelchair Passenger Vertical Acceleration, Light Load, 30 mph.

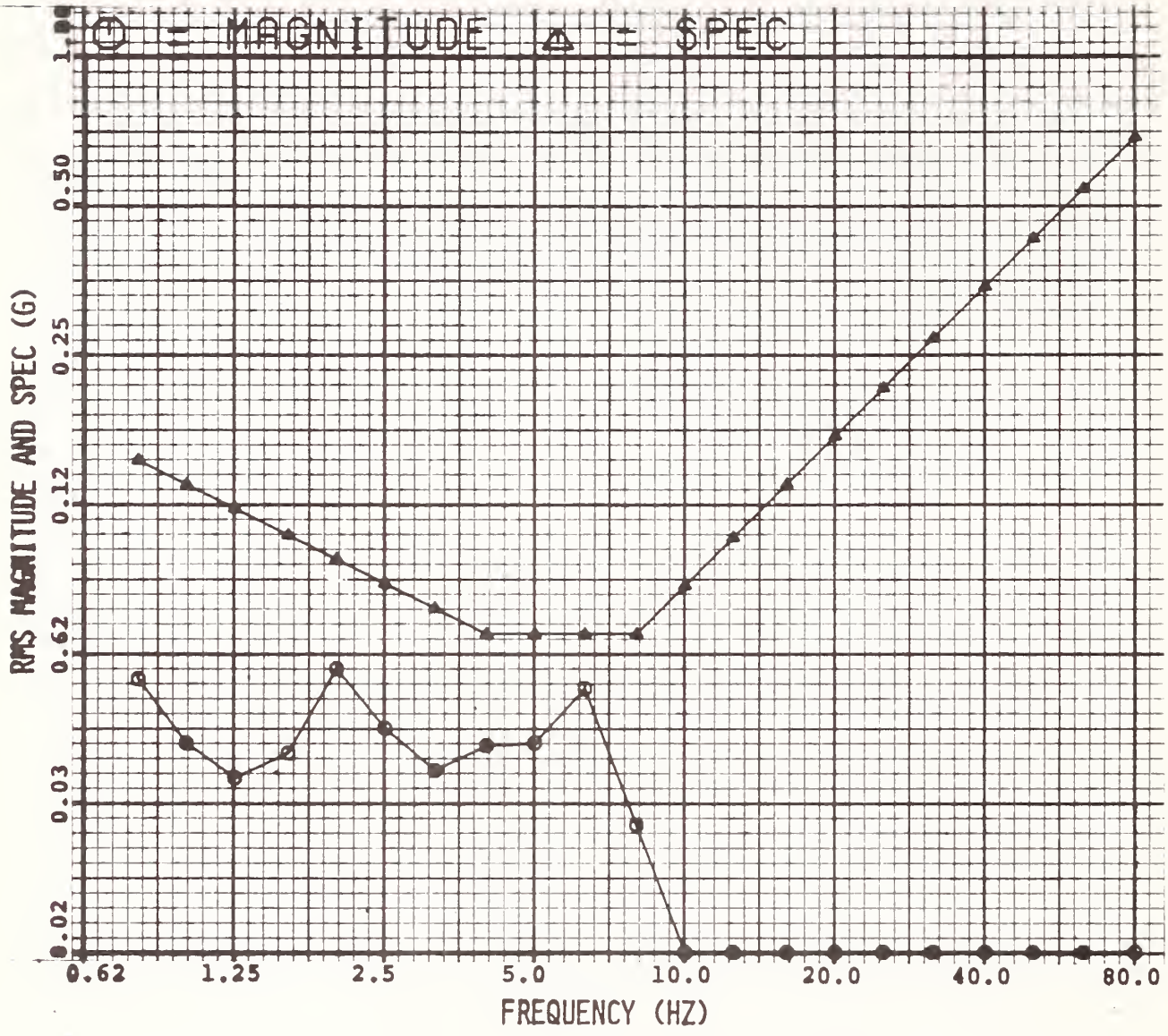


Figure D-21. Dutcher Wheelchair Passenger Vertical Acceleration, Light Load, 40 mph.

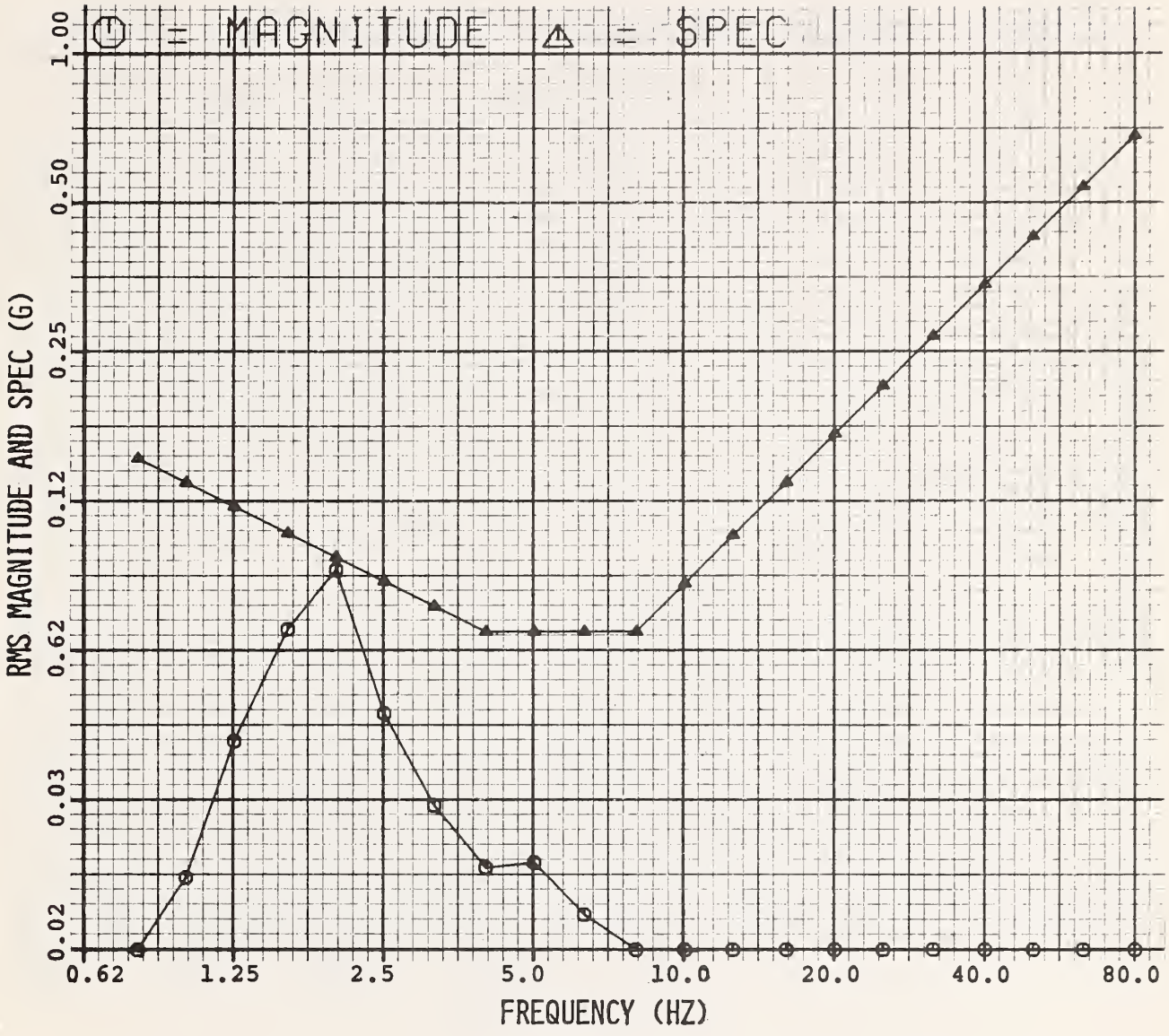


Figure D-22. Dutcher Rear Seat Passenger Vertical Acceleration, Light Load, 5 mph.

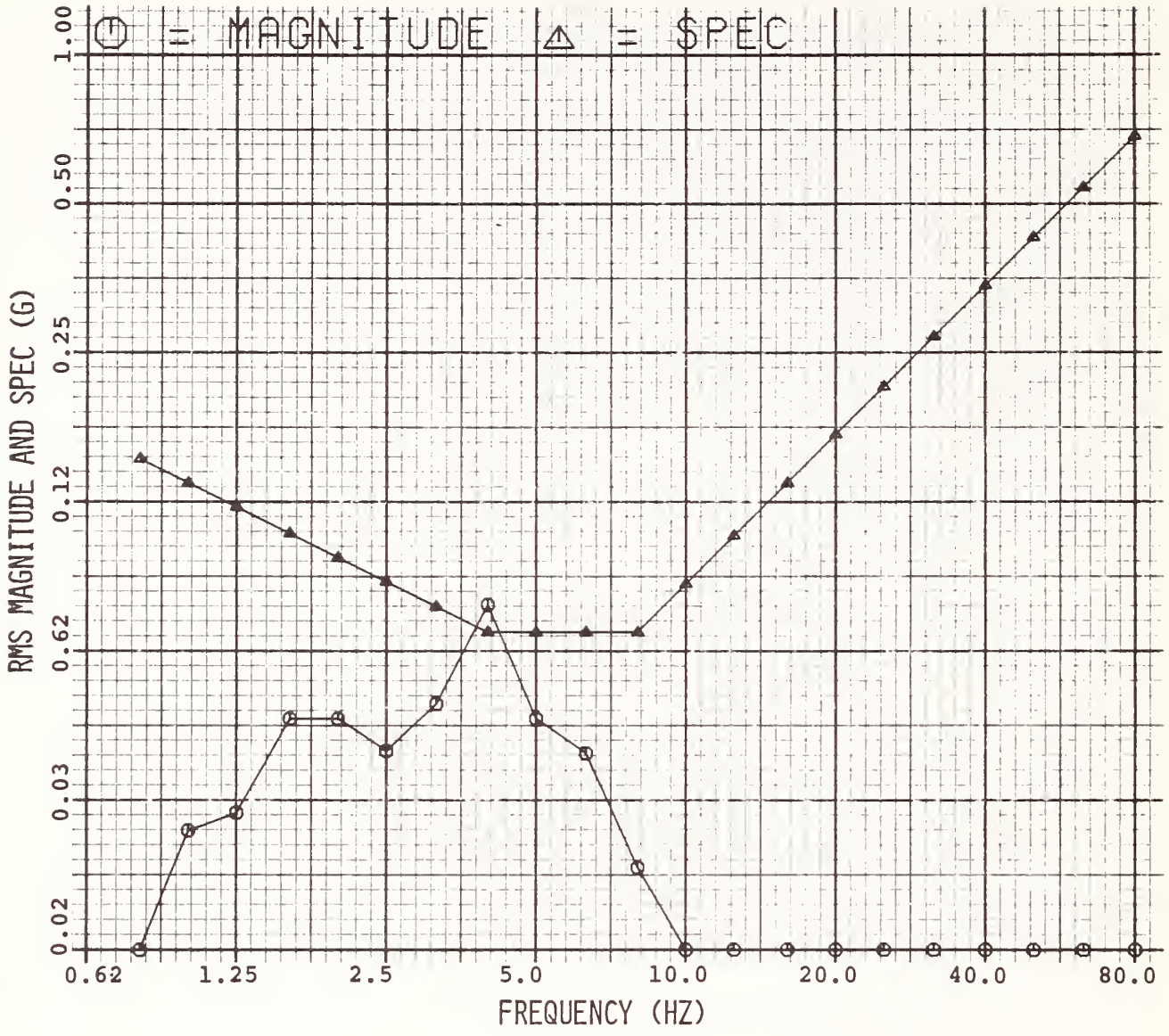


Figure D-23. Dutcher Rear Seat Passenger Vertical Acceleration, Light Load, 10 mph.

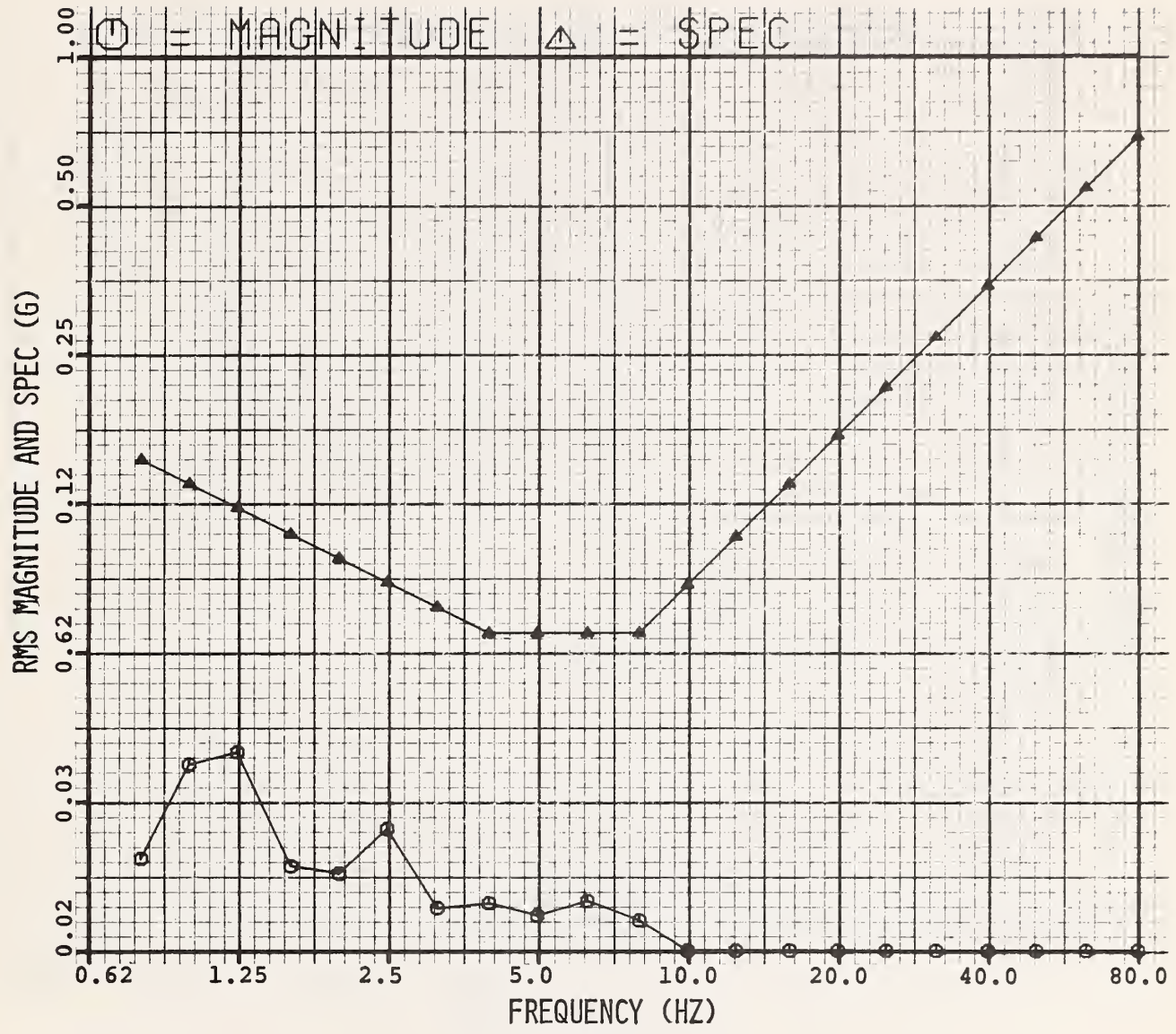


Figure D-24. Dutcher Rear Seat Passenger Vertical Acceleration, Light Load, 20 mph.

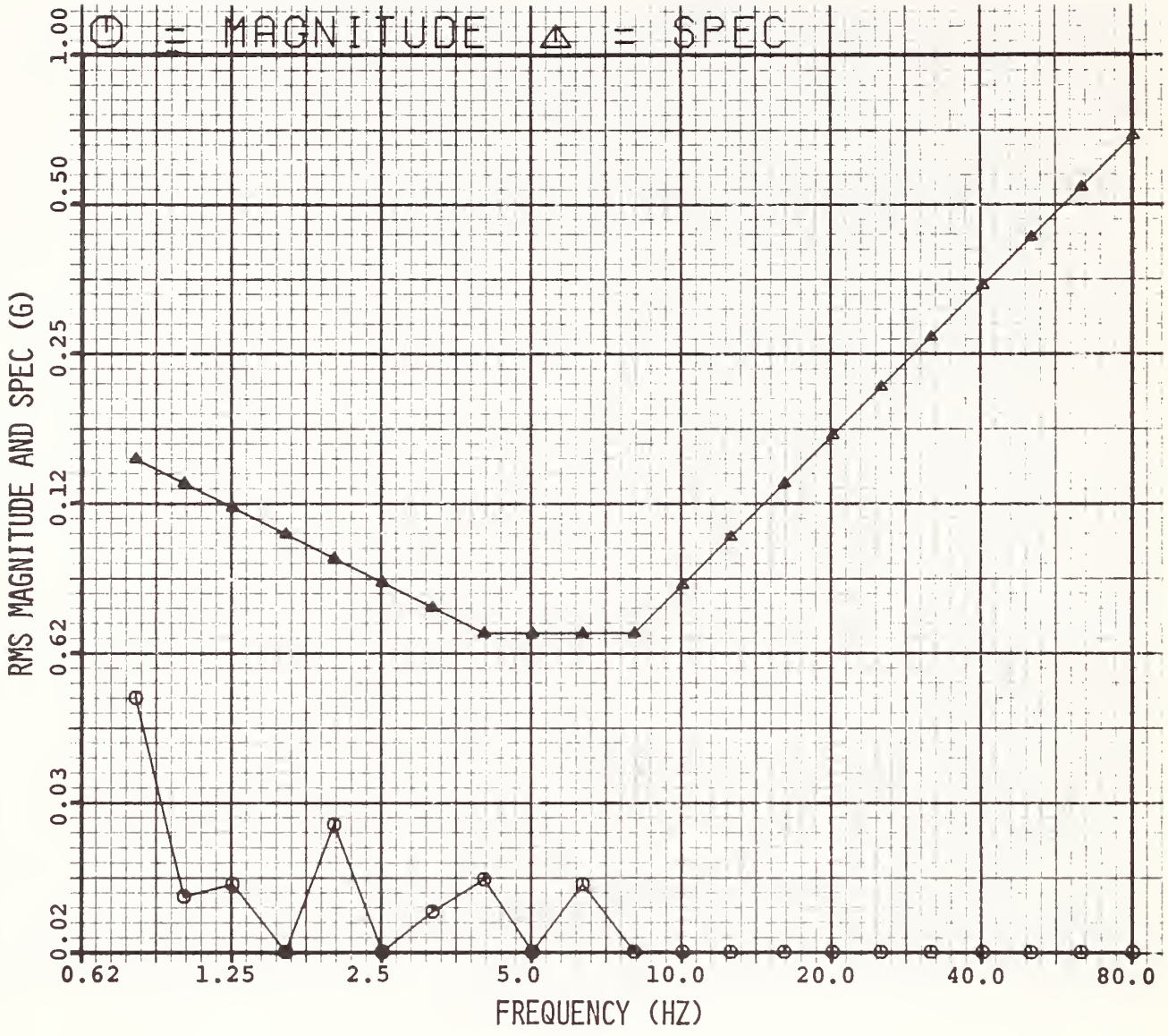


Figure D-25. Dutcher Rear Seat Passenger Vertical Acceleration, Light Load, 30 mph.

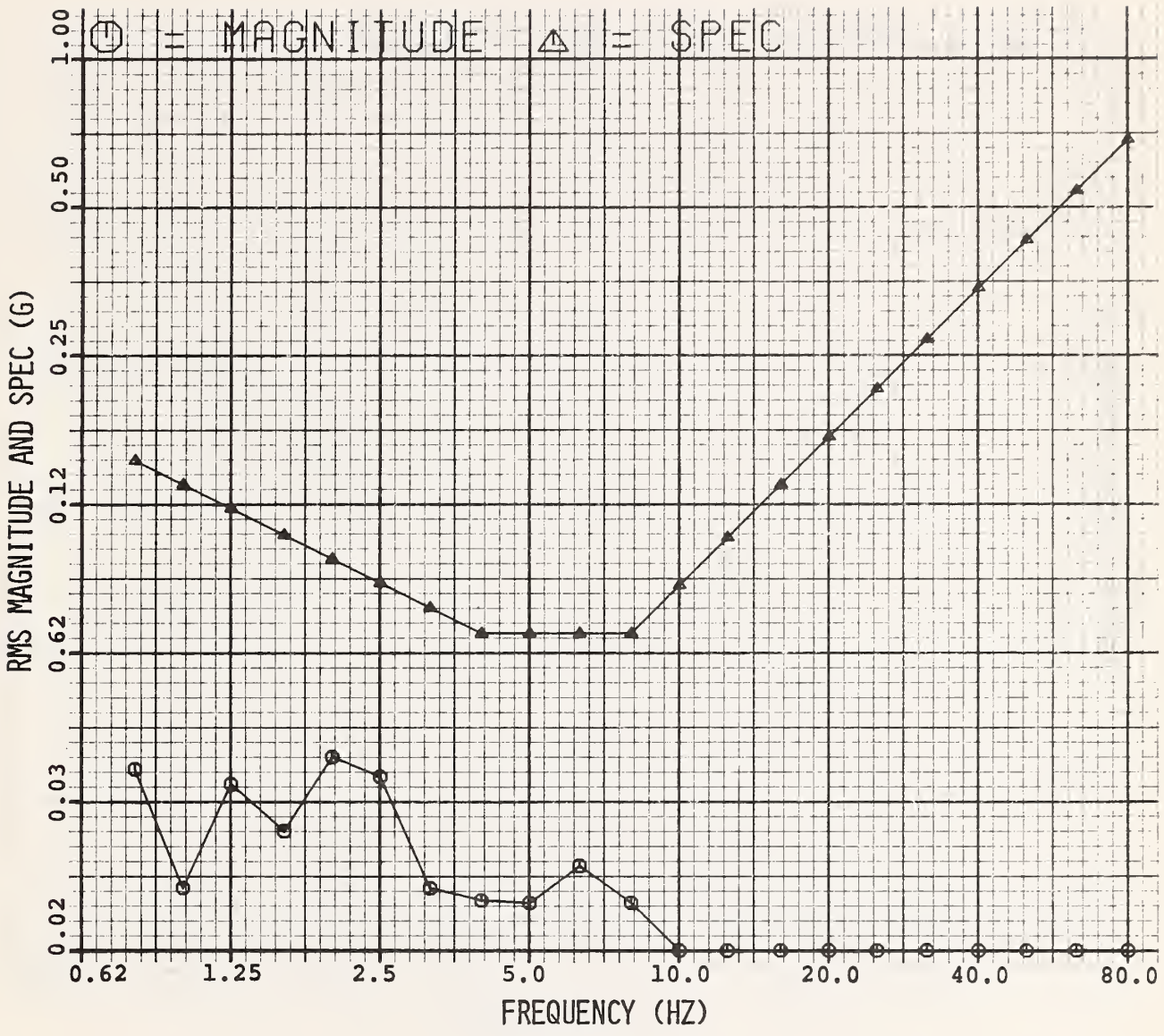


Figure D-26. Dutcher Rear Seat Passenger Vertical Acceleration, Light Load, 40 mph.

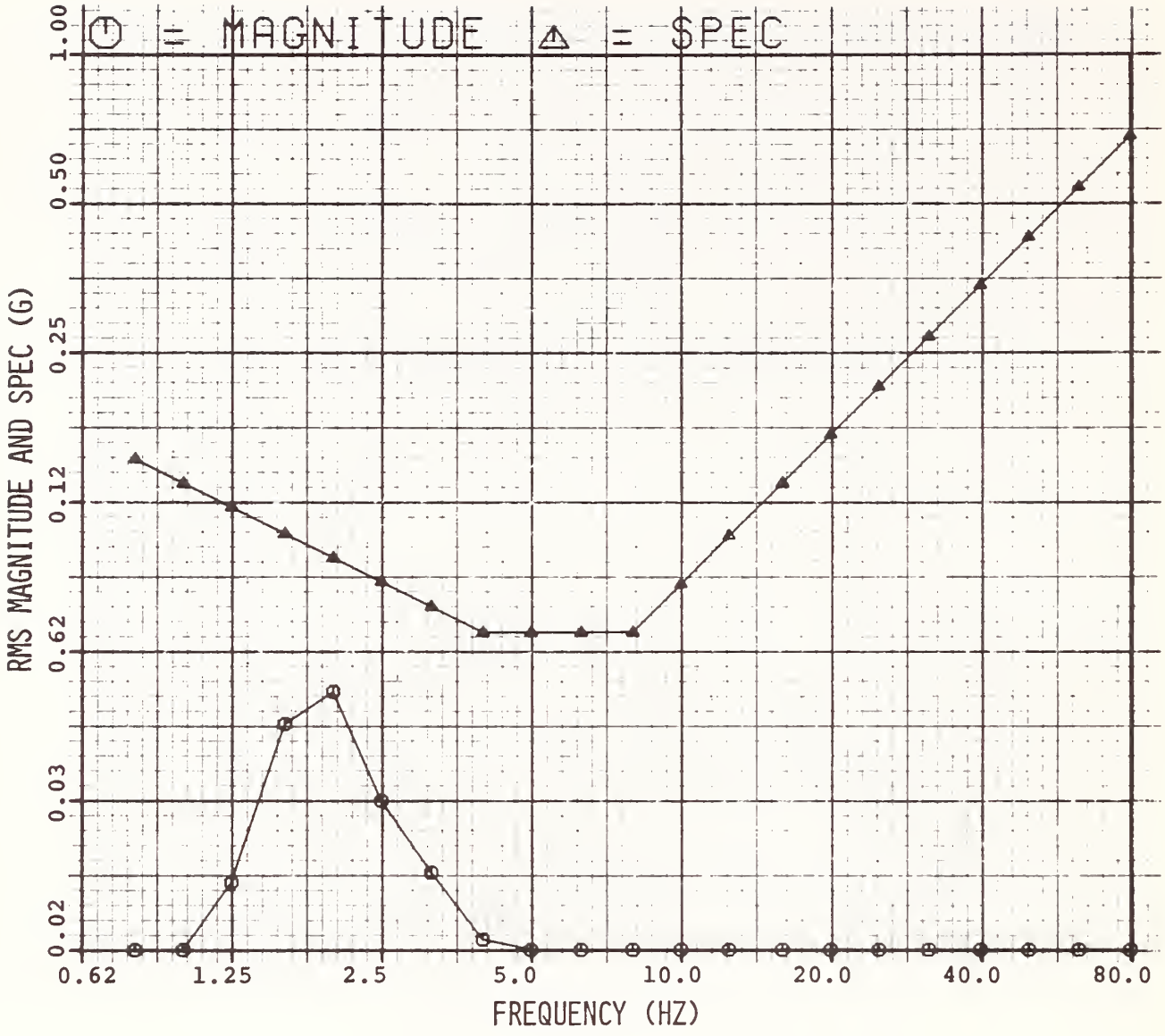


Figure D-27. Dutcher Wheelchair Passenger Vertical Acceleration, Heavy Load, 5 mph.

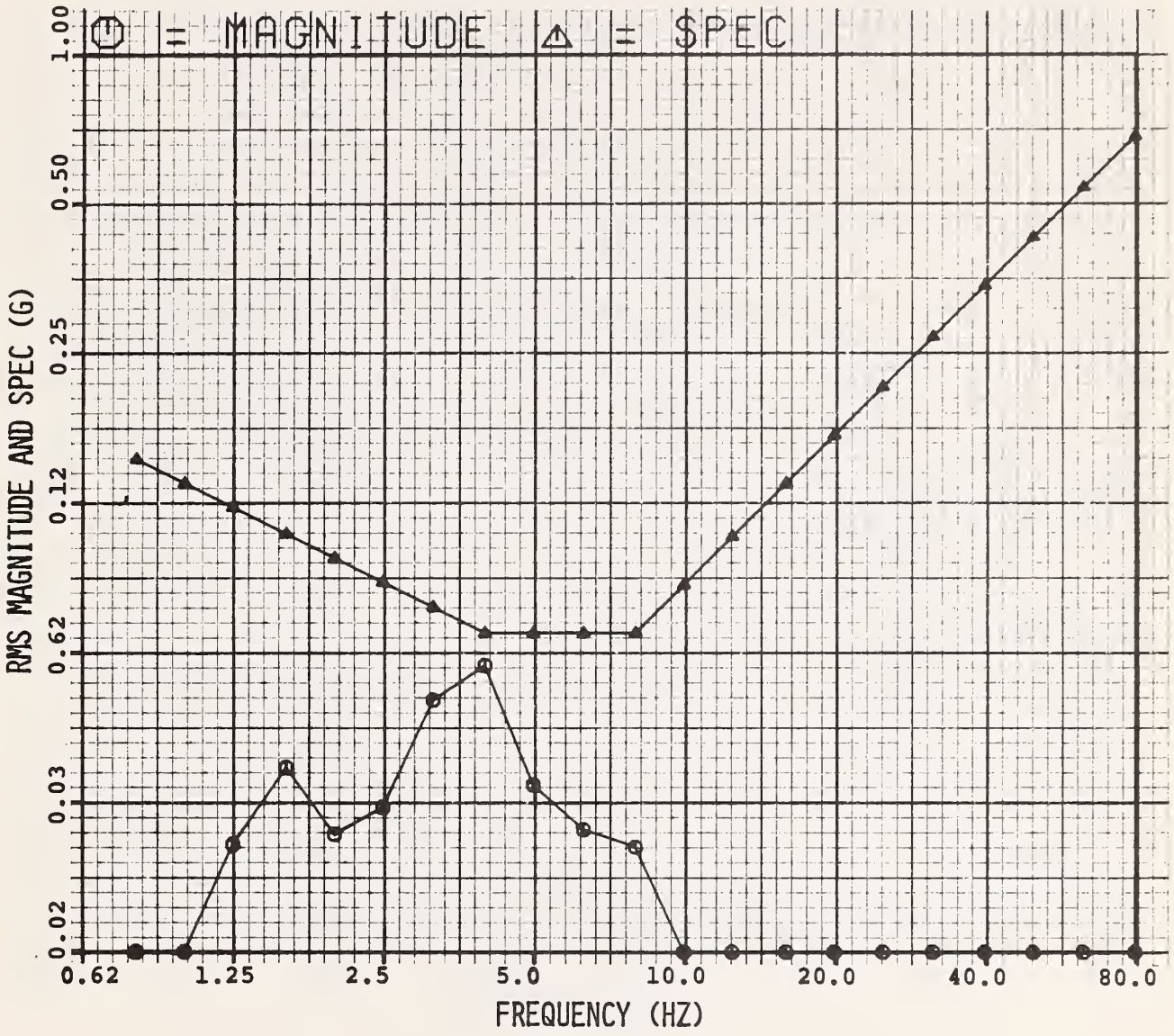


Figure D-28. Dutcher Wheelchair Passenger Vertical Acceleration, Heavy Load, 10 mph.

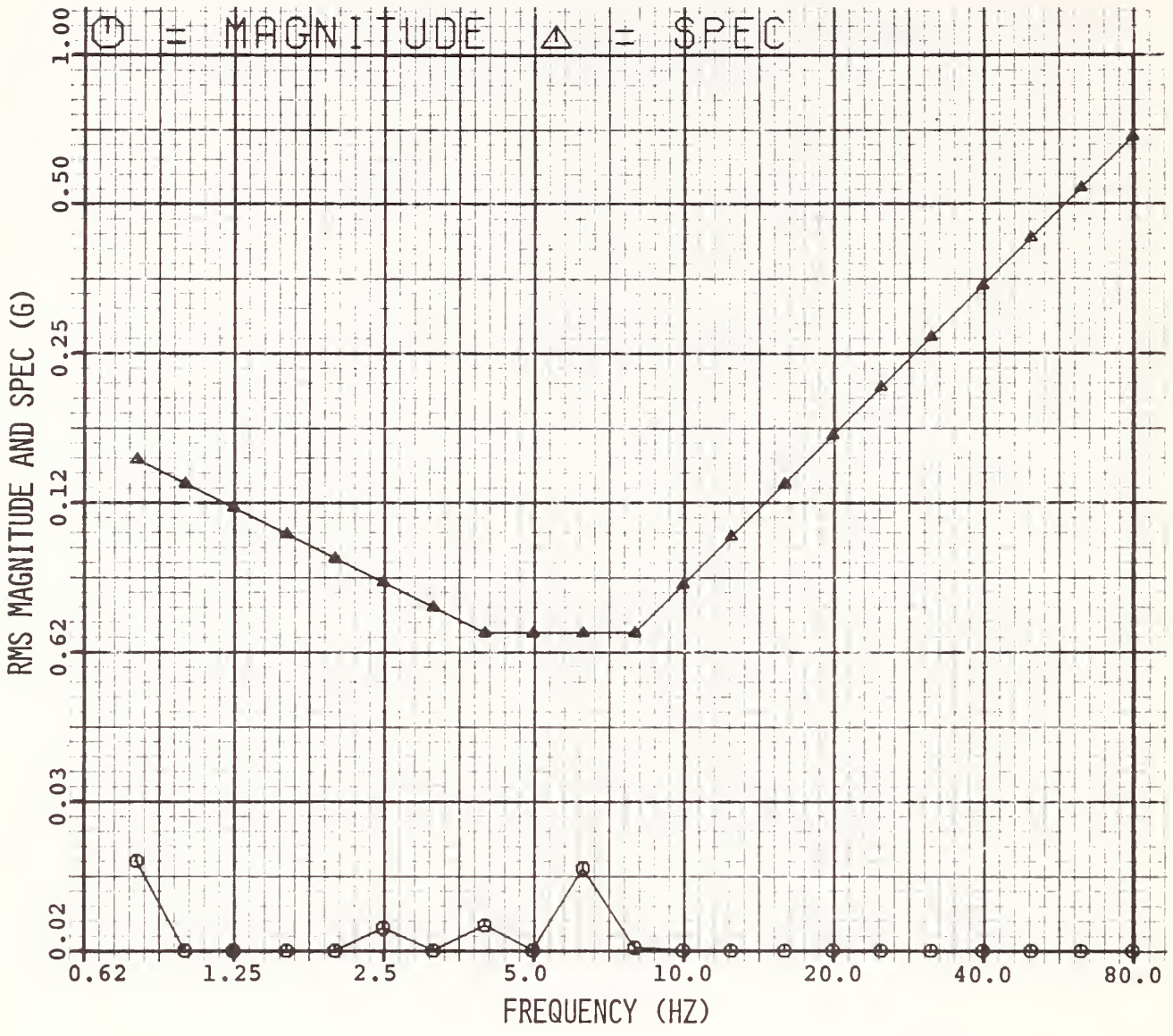


Figure D-29. Dutcher Wheelchair Passenger Vertical Acceleration, Heavy Load, 20 mph.

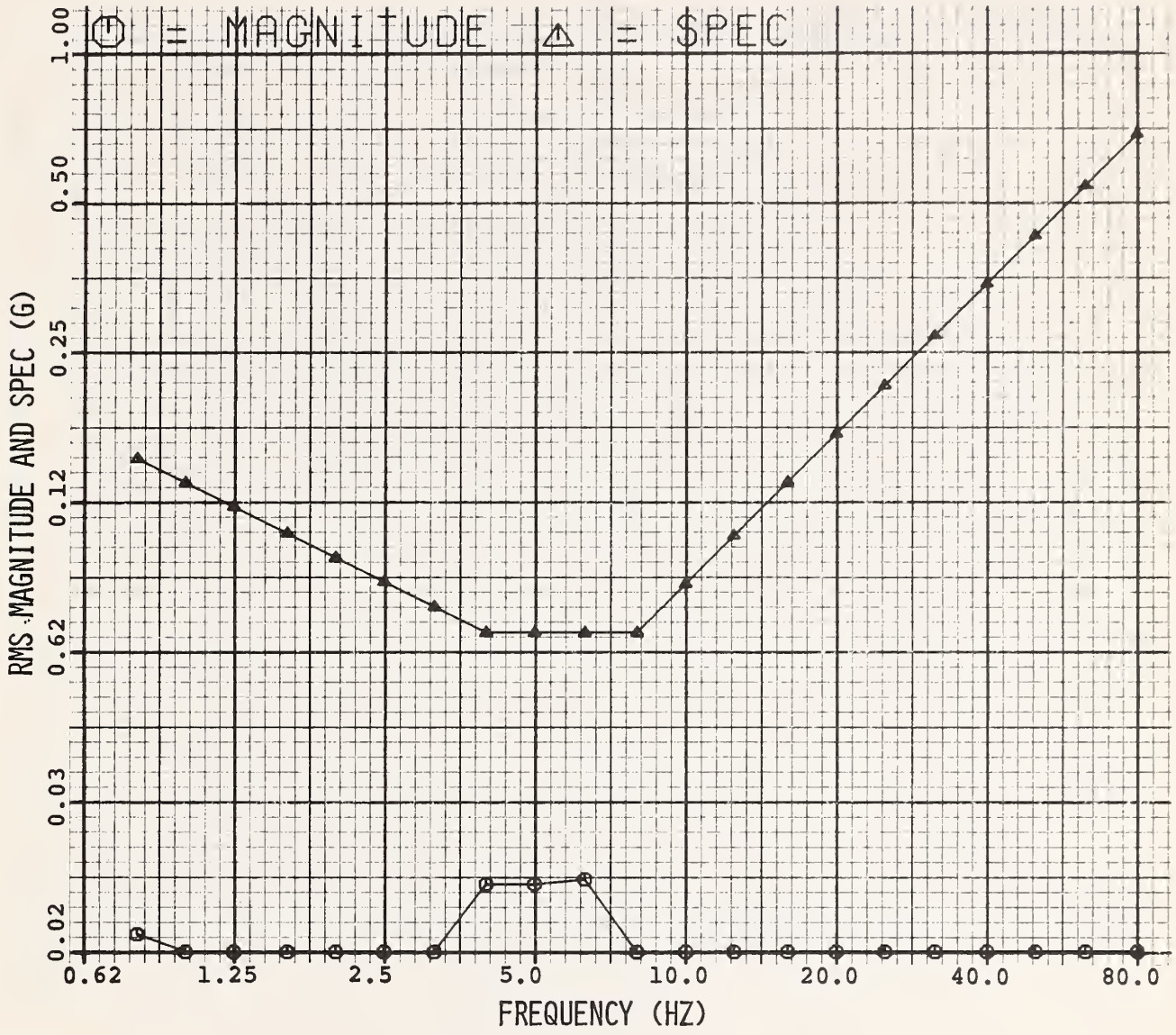


Figure D-30. Dutcher Wheelchair Passenger Vertical Acceleration, Heavy Load, 30 mph.

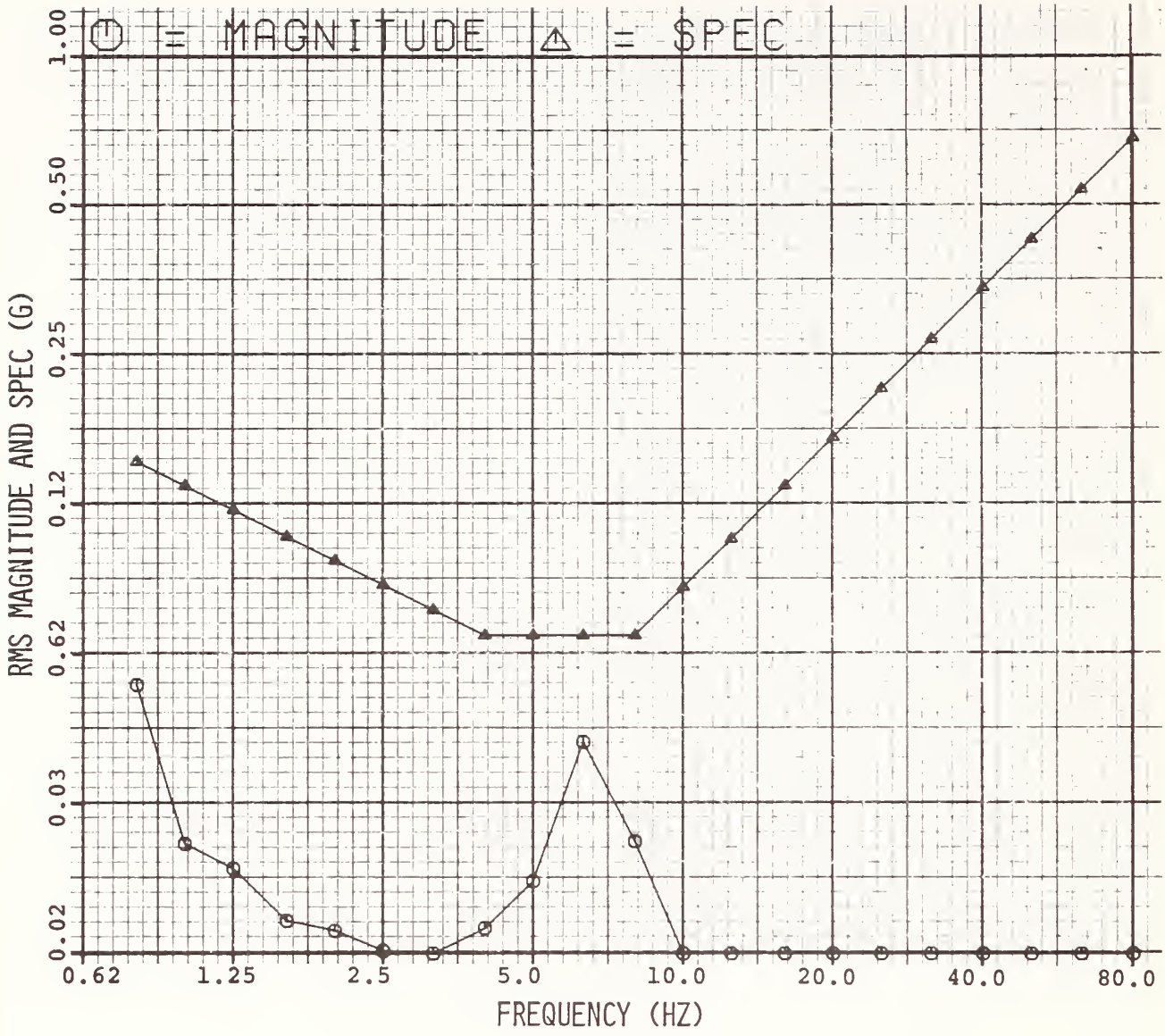


Figure D-31. Dutcher Wheelchair Passenger Vertical Acceleration, Heavy Load, 40 mph.

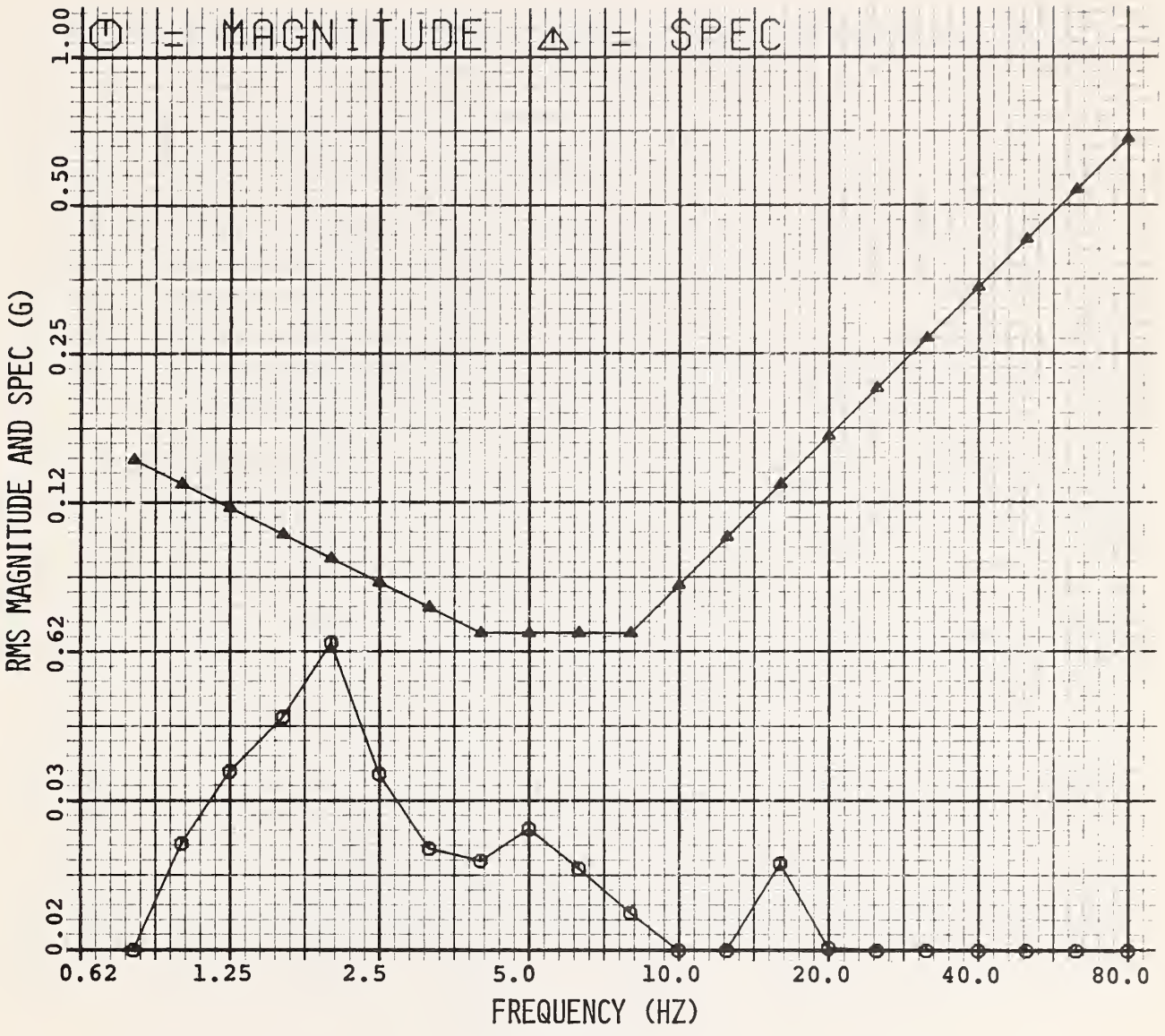


Figure D-32. Dutcher Rear Seat Passenger Vertical Acceleration, Heavy Load, 5 mph.

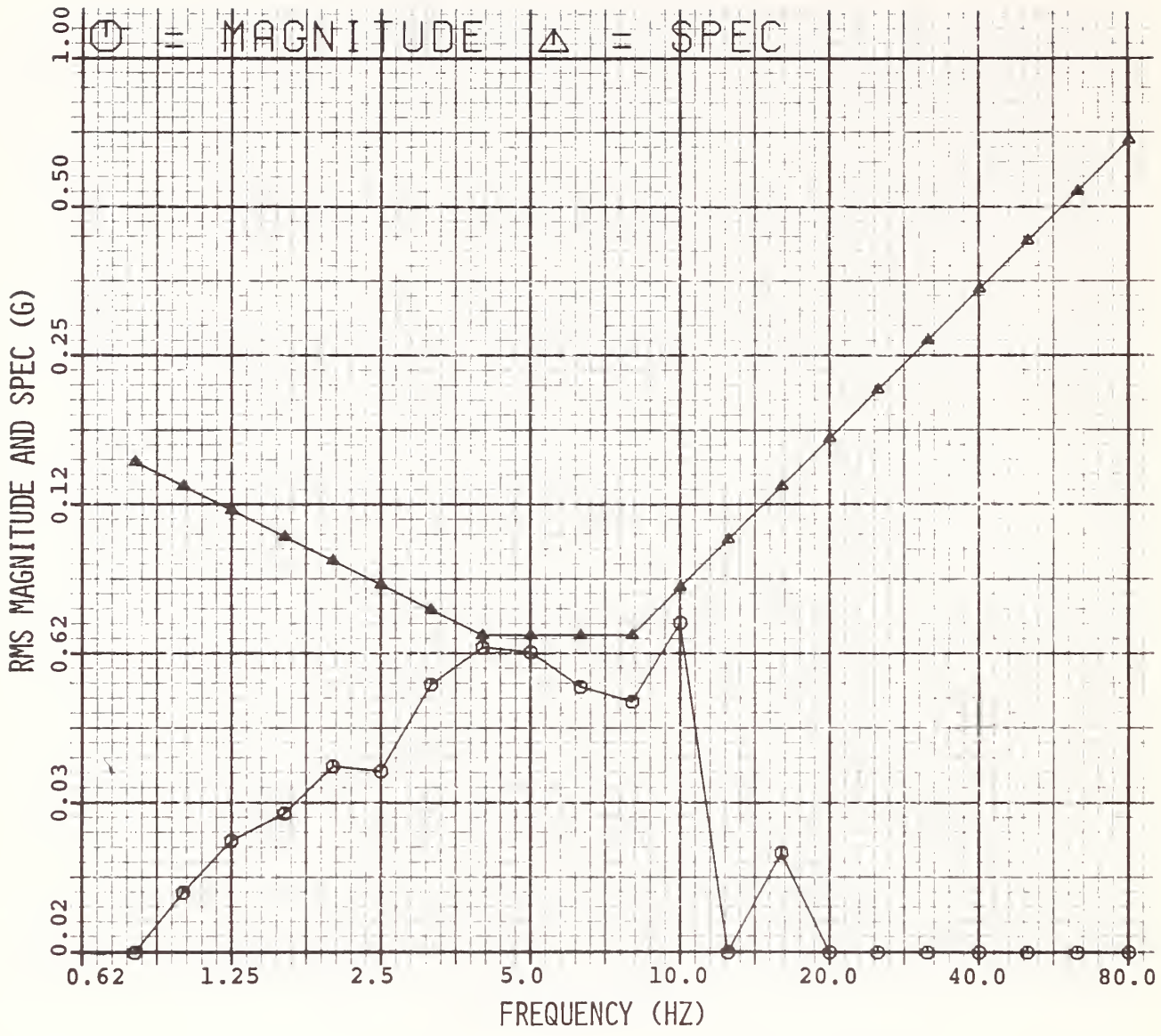


Figure D-33. Dutcher Rear Seat Passenger Vertical Acceleration, Heavy Load, 10 mph.

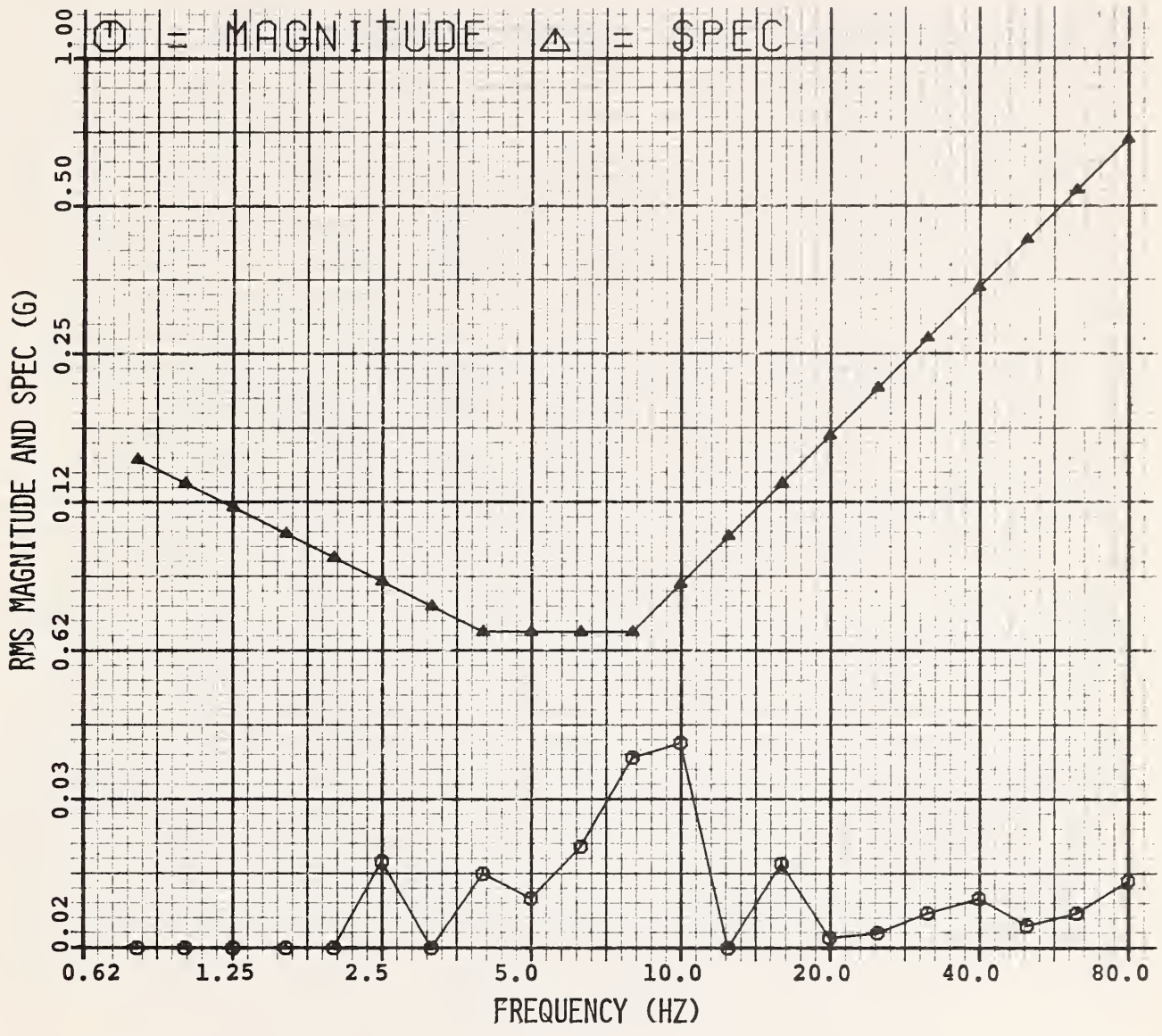


Figure D-34. Dutcher Rear Seat Passenger Vertical Acceleration, Heavy Load, 20 mph.

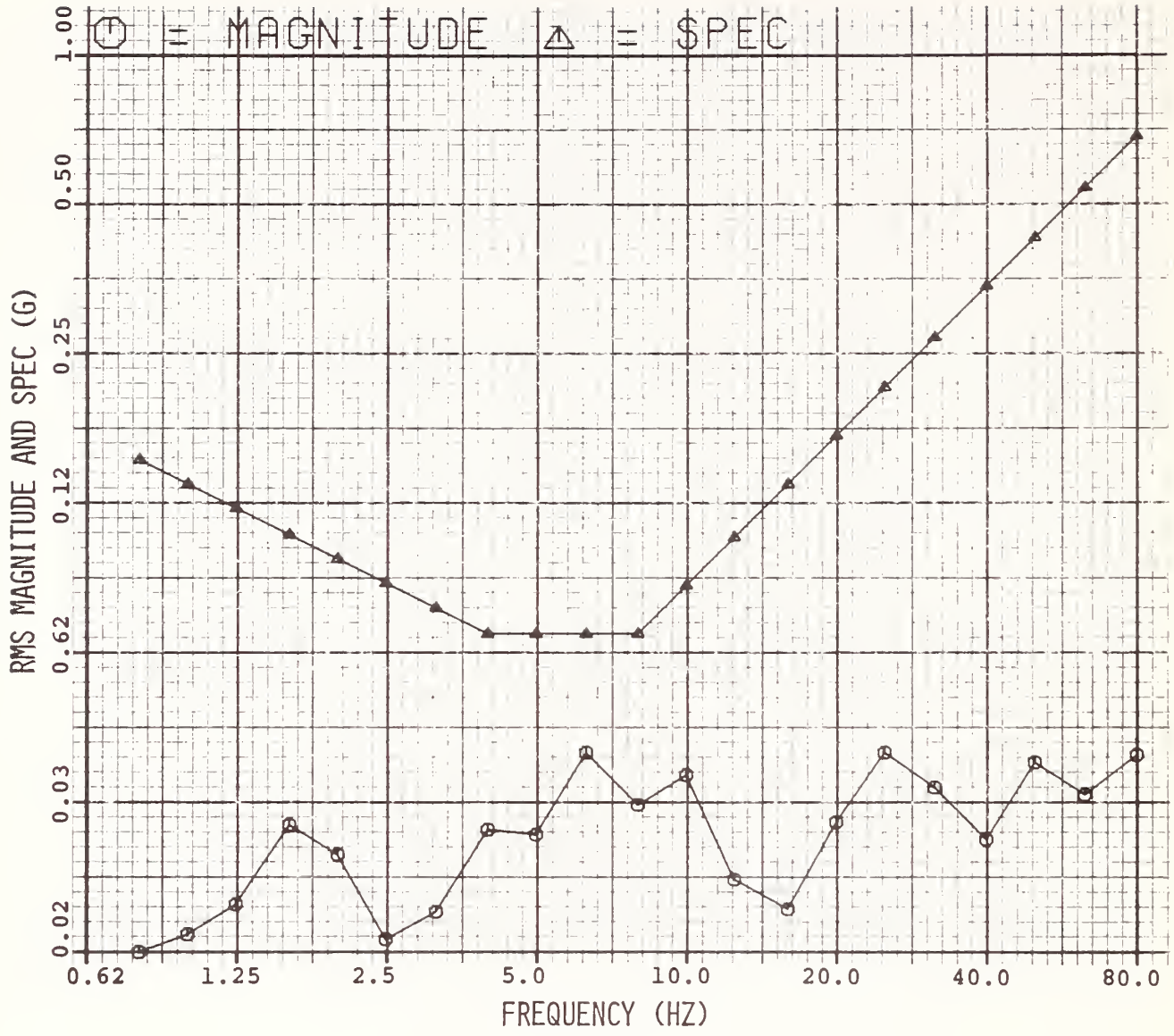


Figure D-35. Dutcher Rear Seat Passenger Vertical Acceleration, Heavy Load, 30 mph.

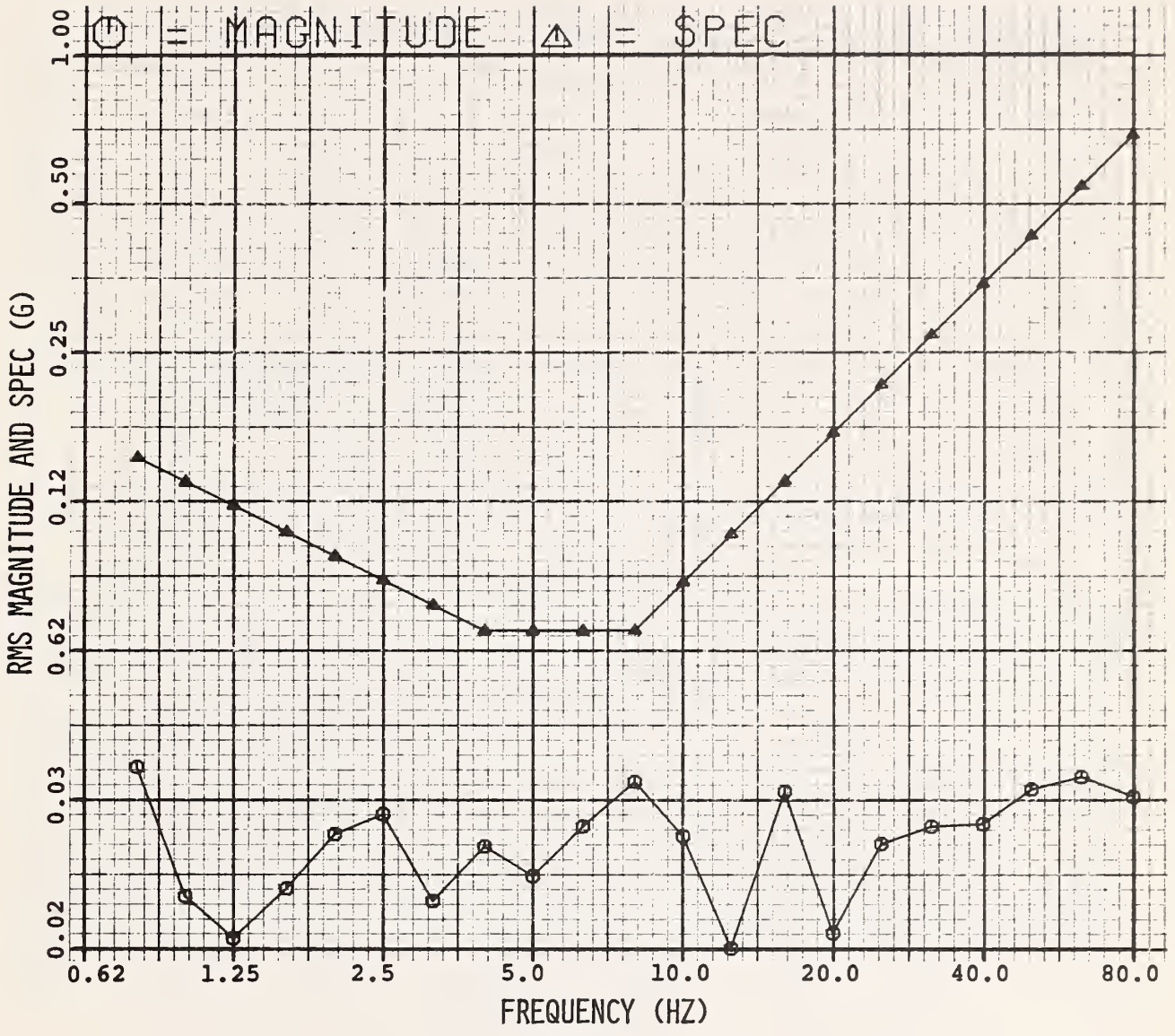


Figure D-36. Dutcher Rear Seat Passenger Vertical Acceleration, Heavy Load, 40 mph.

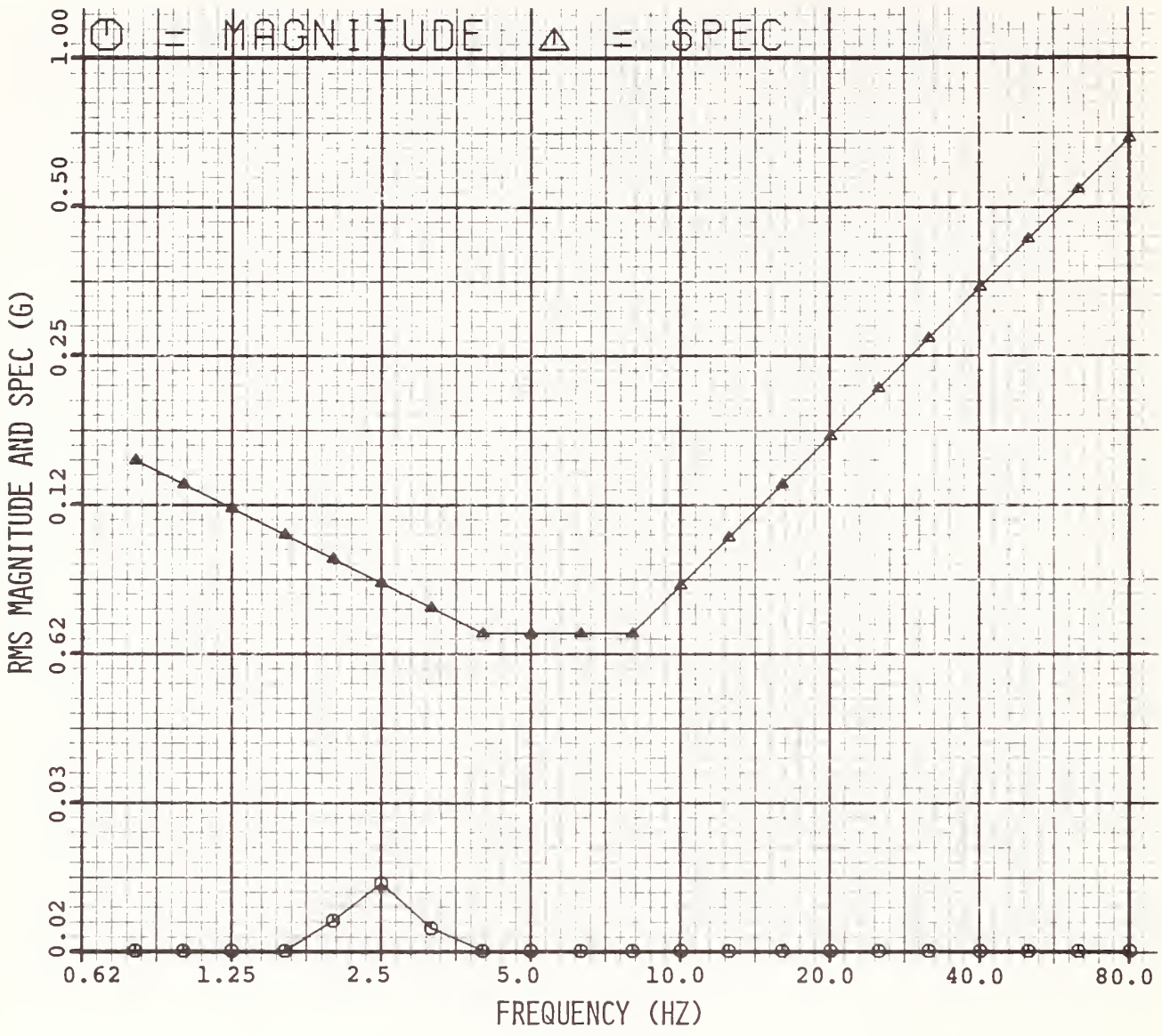


Figure D-37. Dutcher Wheelchair Passenger Vertical Acceleration, Urban Driving Course.

APPENDIX E

VEHICLE ROLL ACCELERATIONS VERSUS FREQUENCY

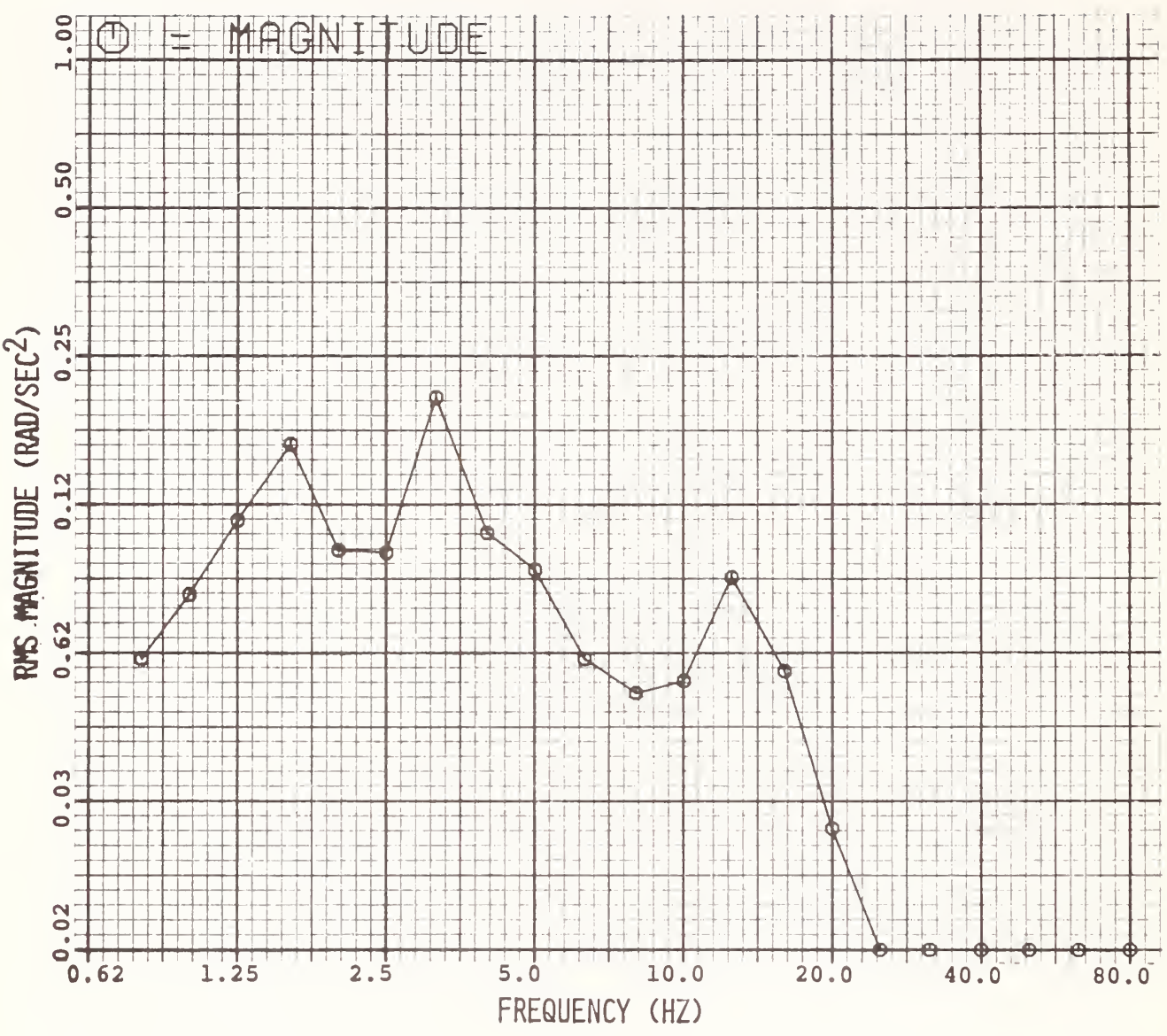


Figure E-1. Nova Vehicle Roll Acceleration, Light Load, 5 mph.

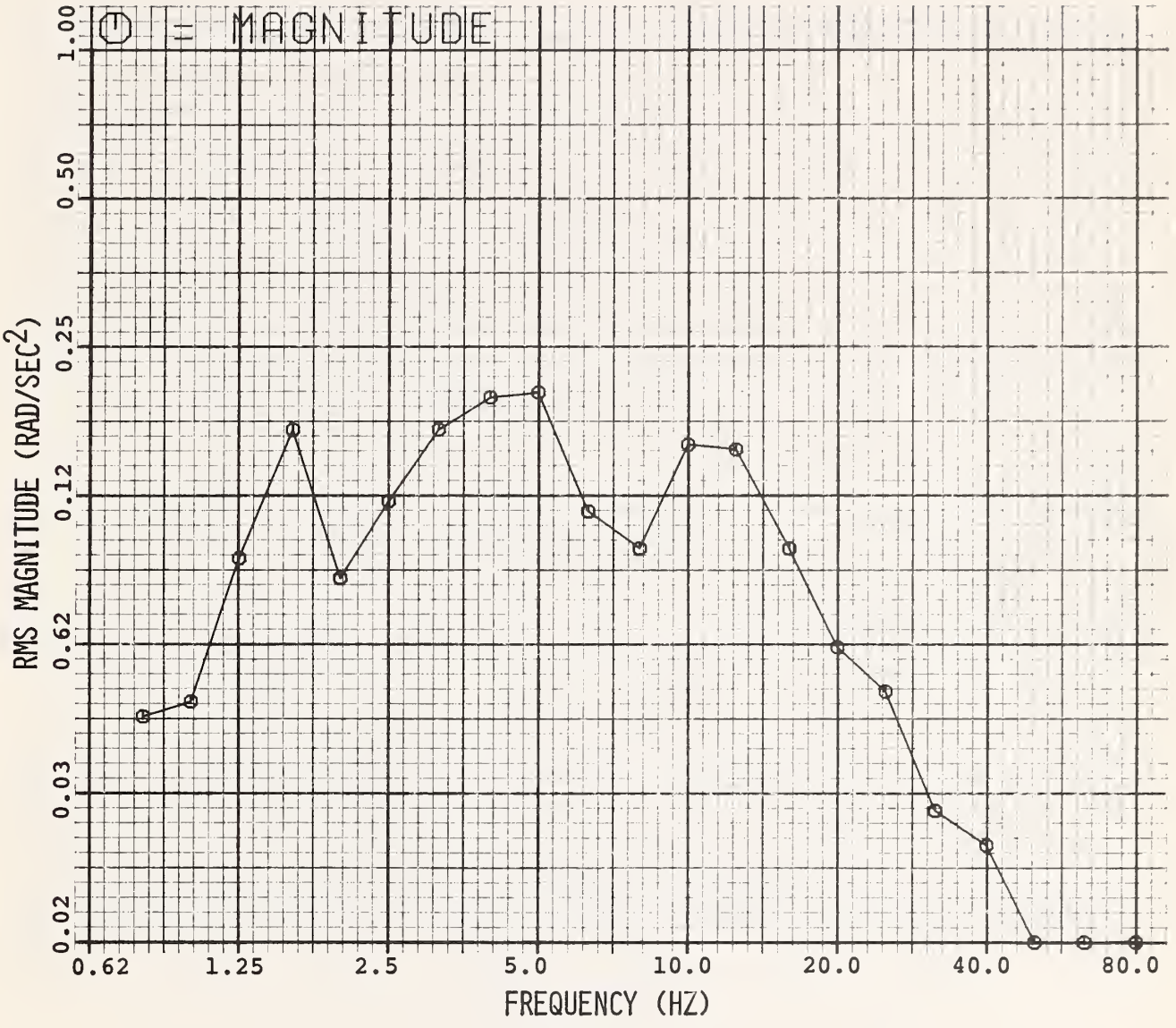


Figure E-2. Nova Vehicle Roll Acceleration, Light Load, 10 mph.

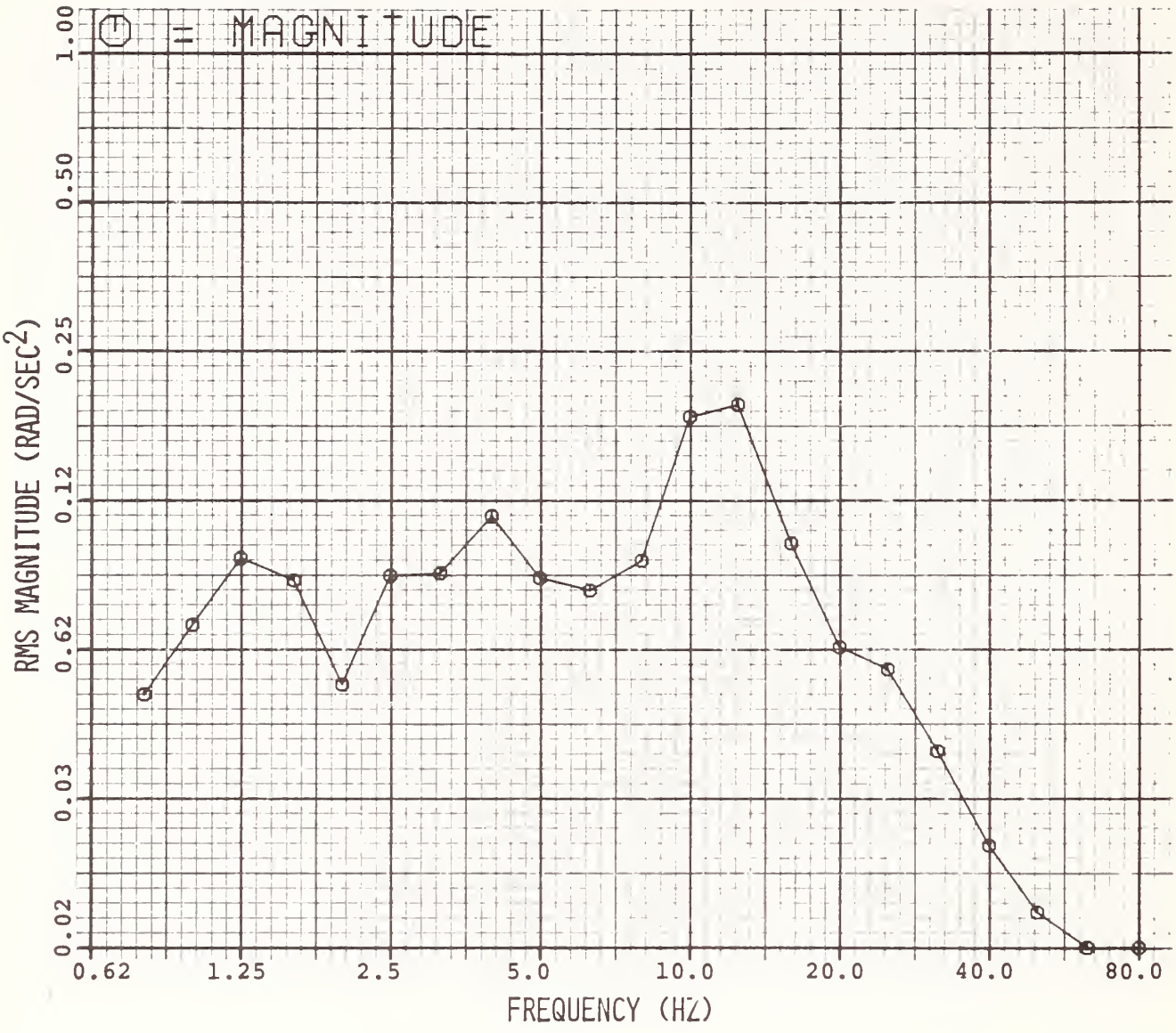


Figure E-3. Nova Vehicle Roll Acceleration, Light Load, 20 mph.

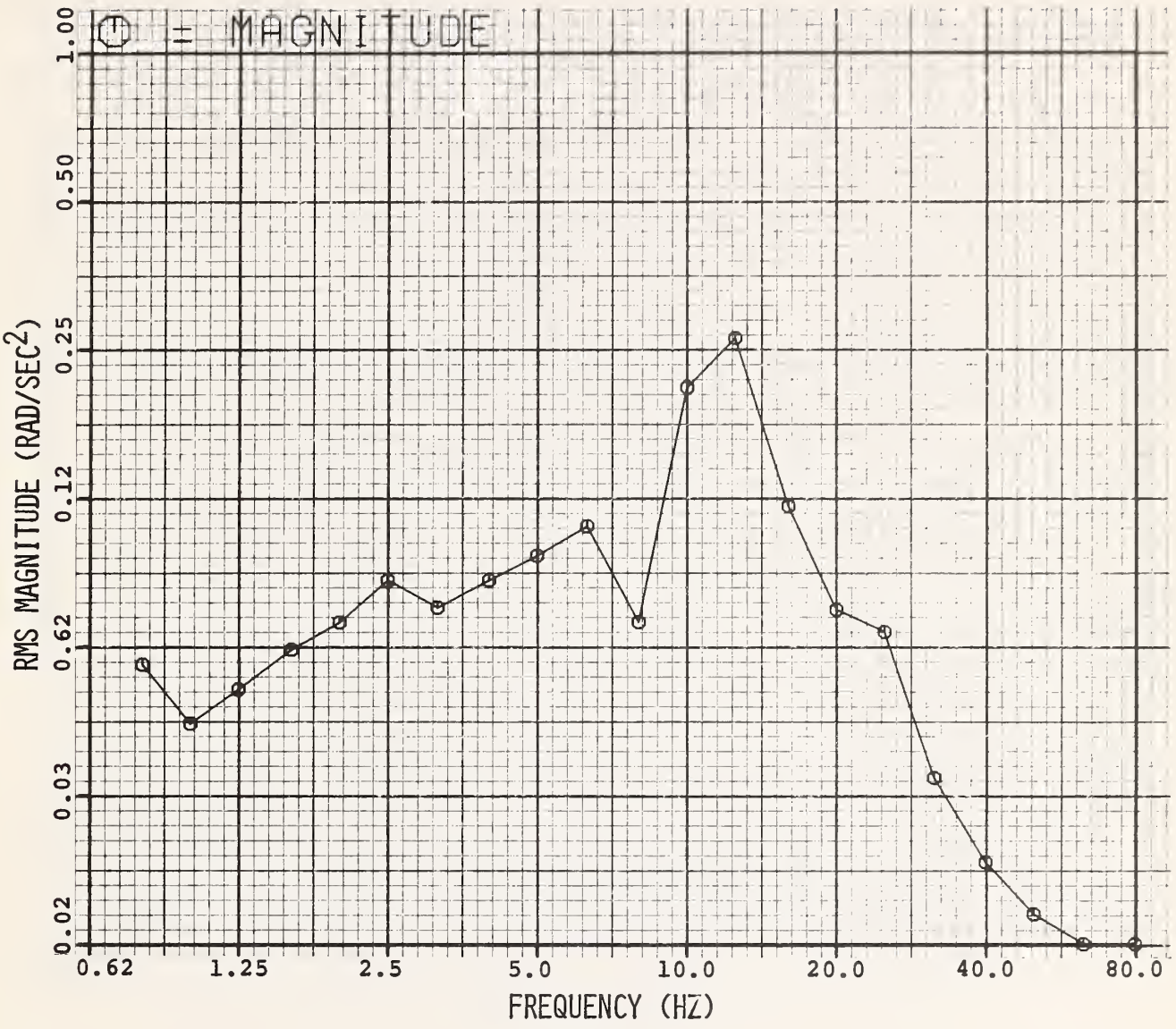


Figure E-4. Nova Vehicle Roll Acceleration, Light Load, 30 mph.

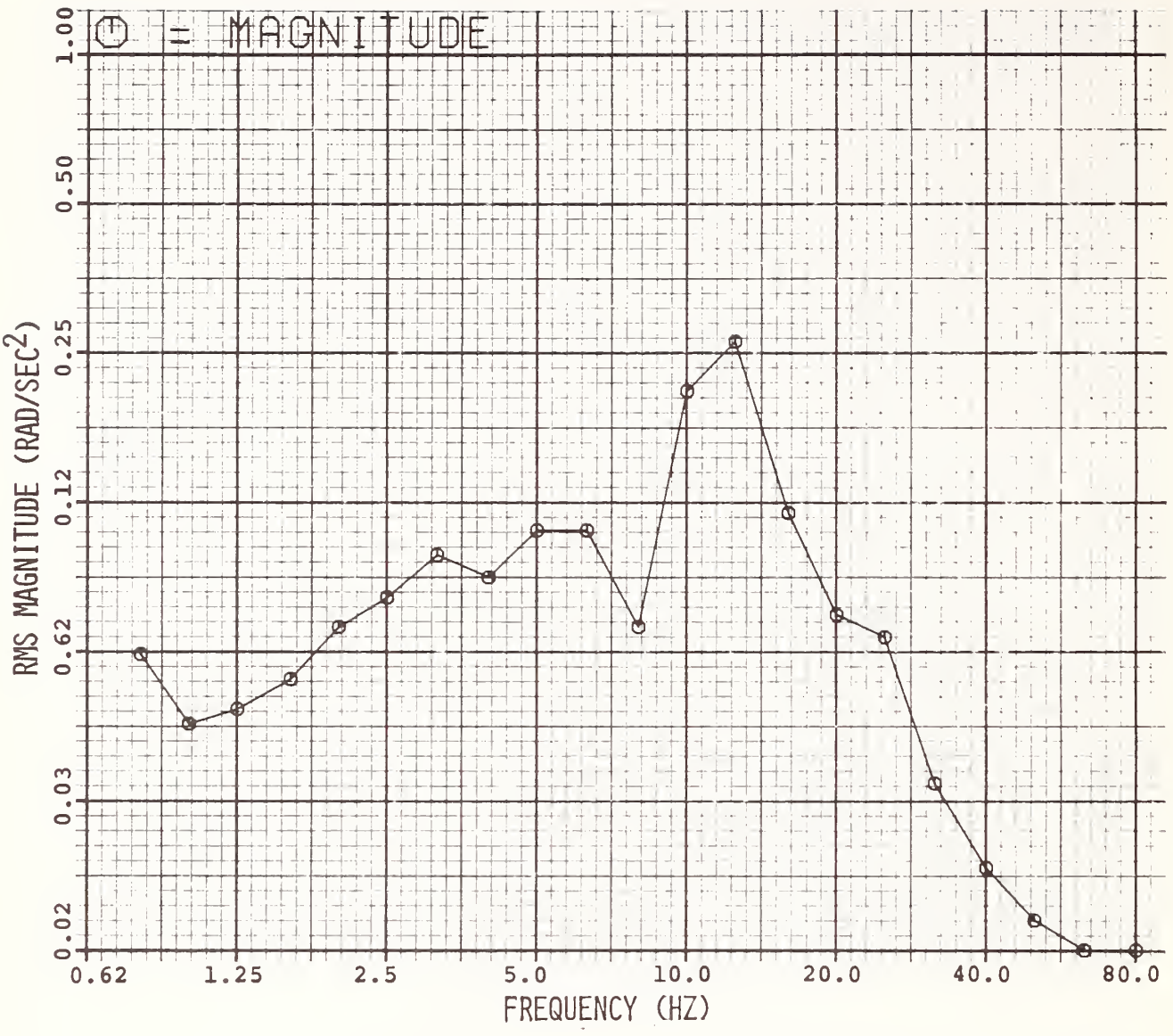


Figure E-5. Nova Vehicle Roll Acceleration, Light Load, 40 mph.

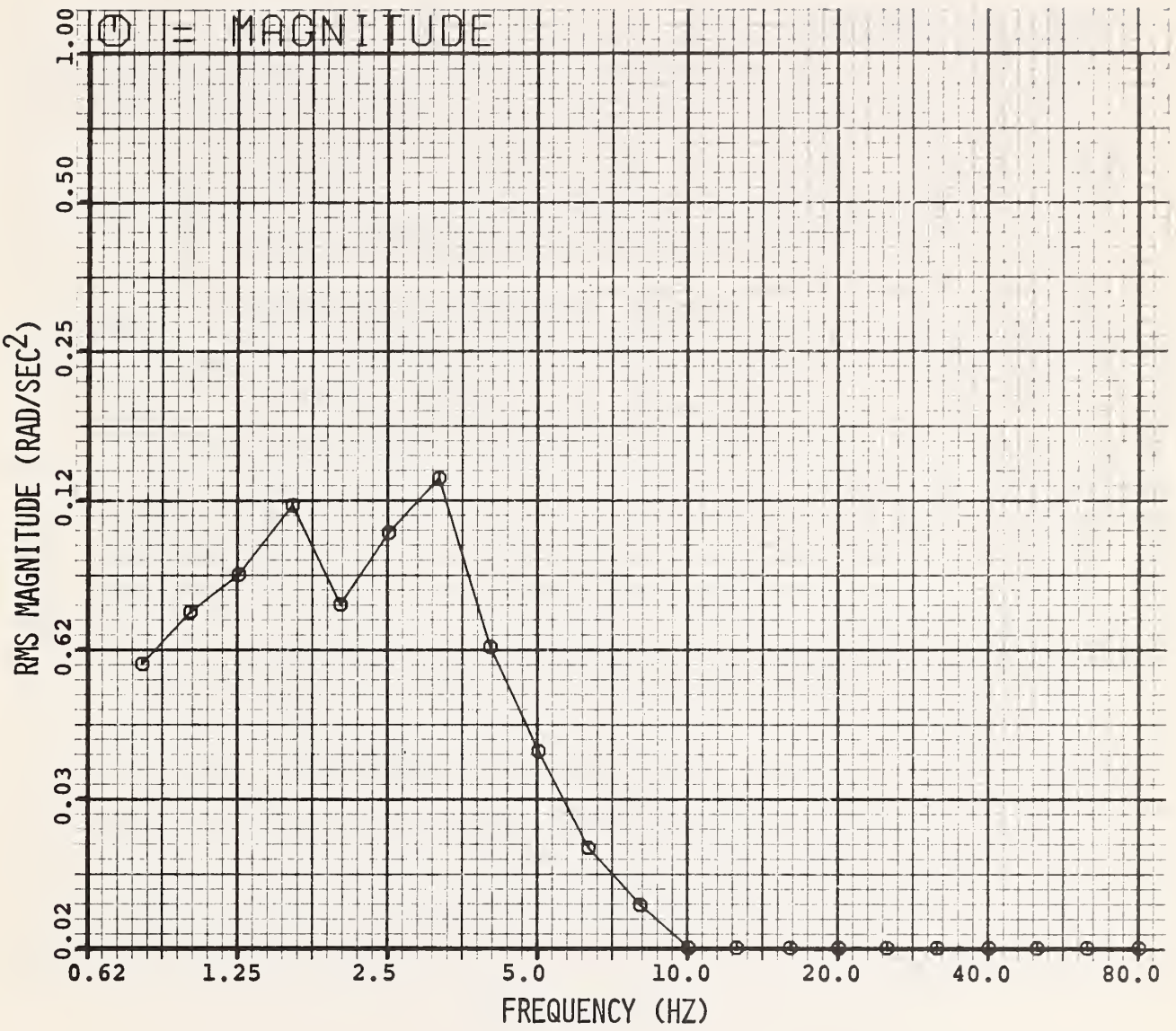


Figure E-6. Nova Vehicle Roll Acceleration, Heavy Load, 5 mph.

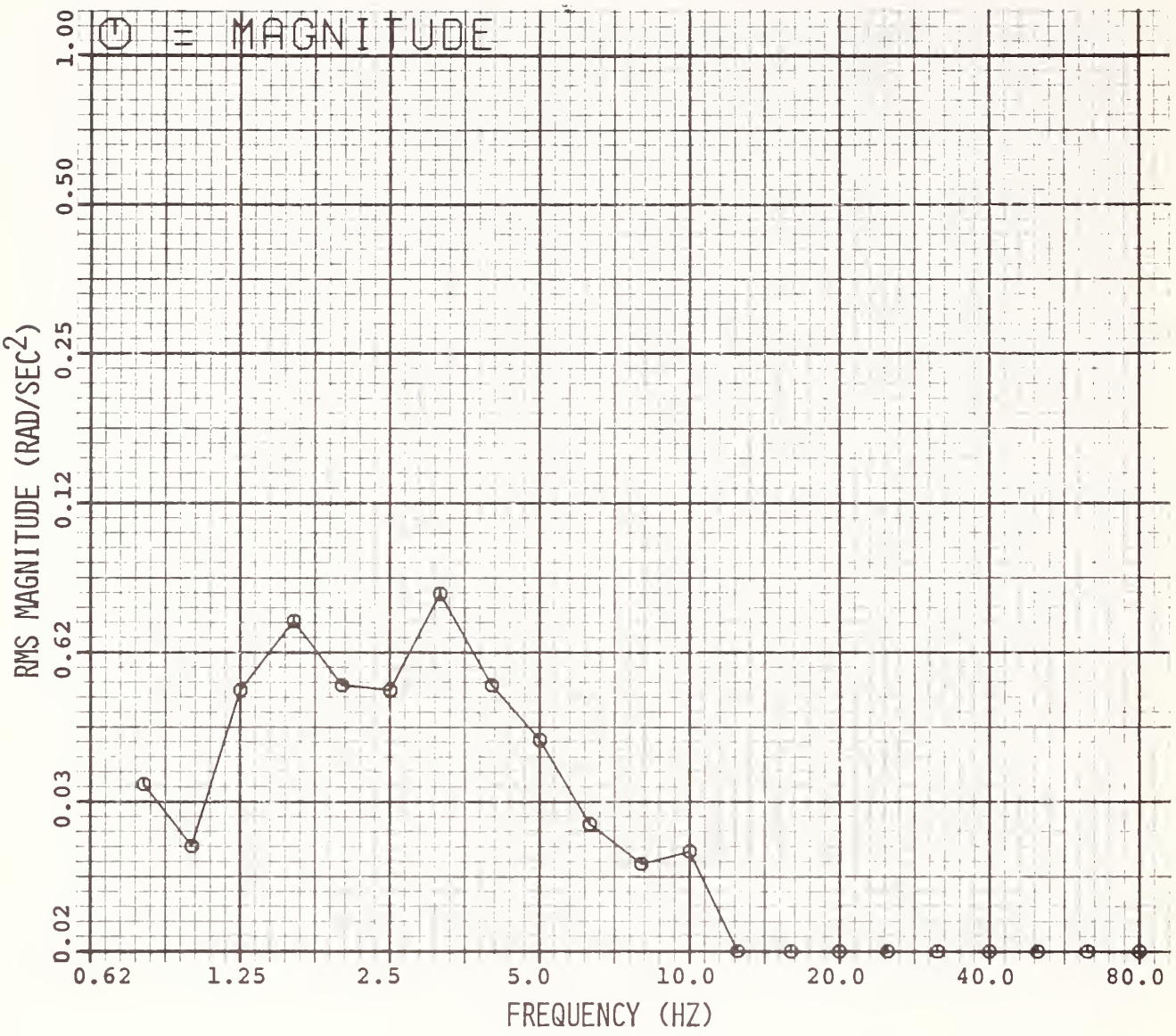


Figure E-7. Nova Vehicle Roll Acceleration, Heavy Load, 10 mph.

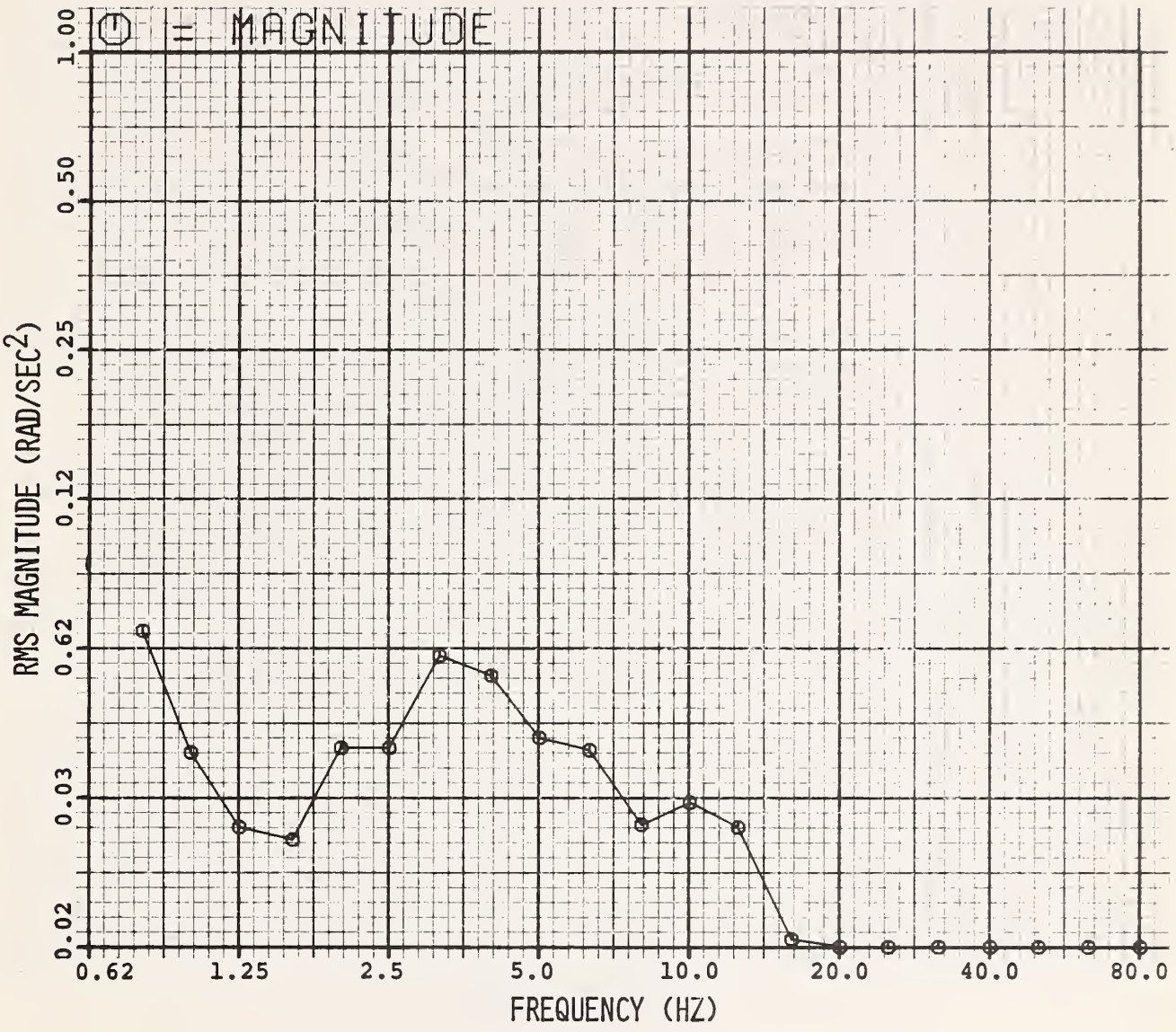


Figure E-8. Nova Vehicle Roll Acceleration, Heavy Load, 20 mph.

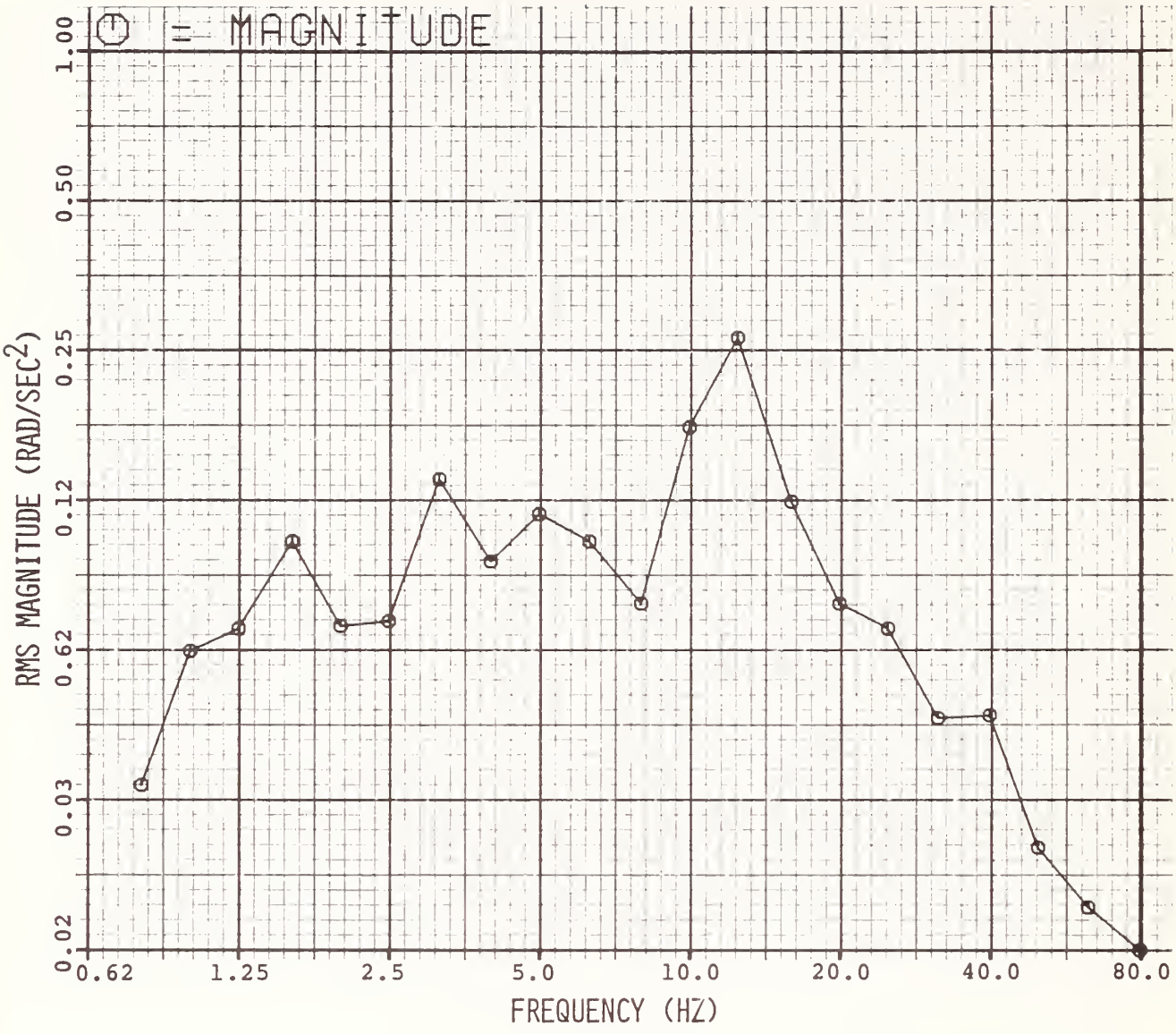


Figure E-9. Nova Vehicle Roll Acceleration, Heavy Load, 30 mph.

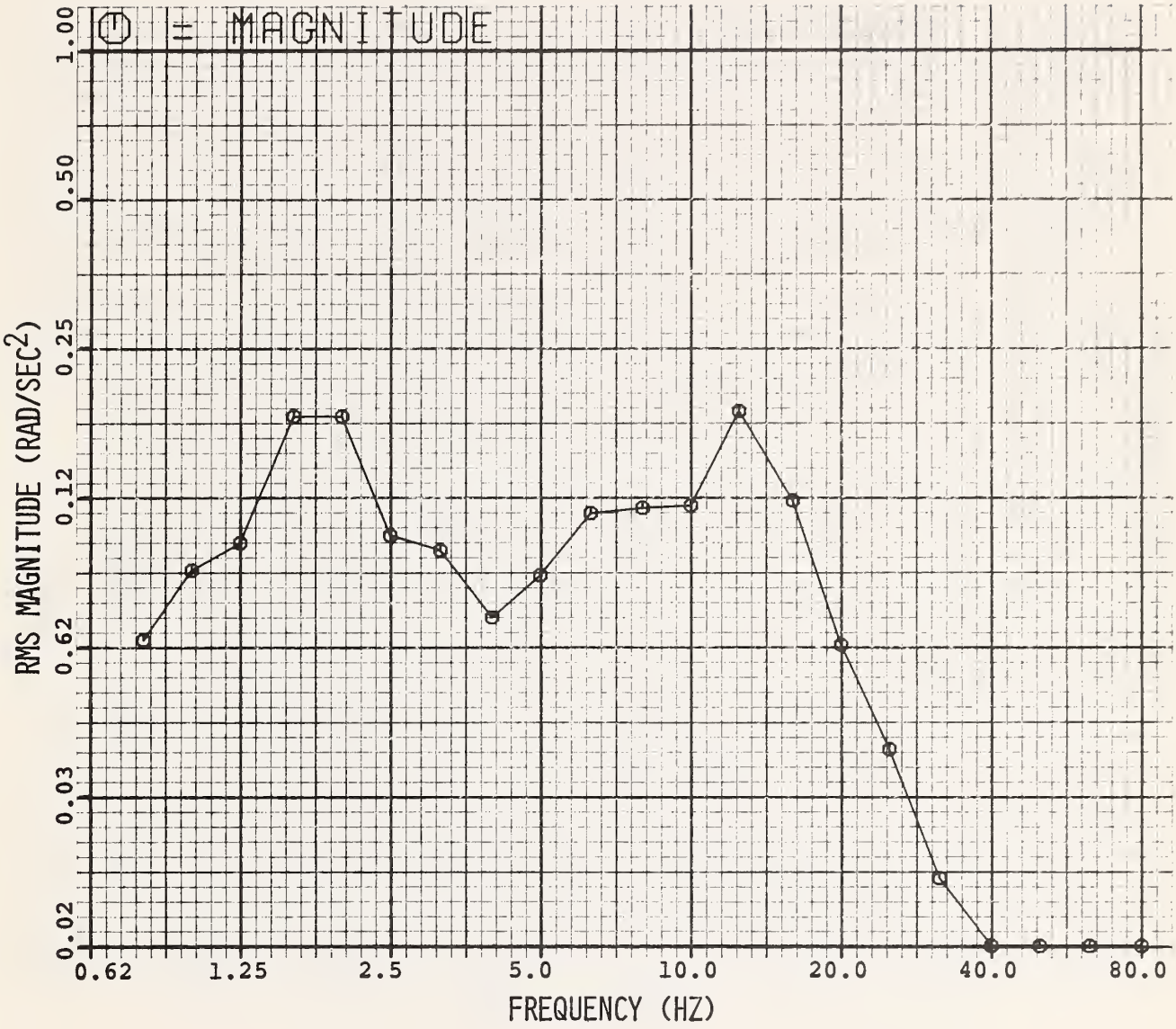


Figure E-10. Nova Vehicle Roll Acceleration, Heavy Load, 40 mph.

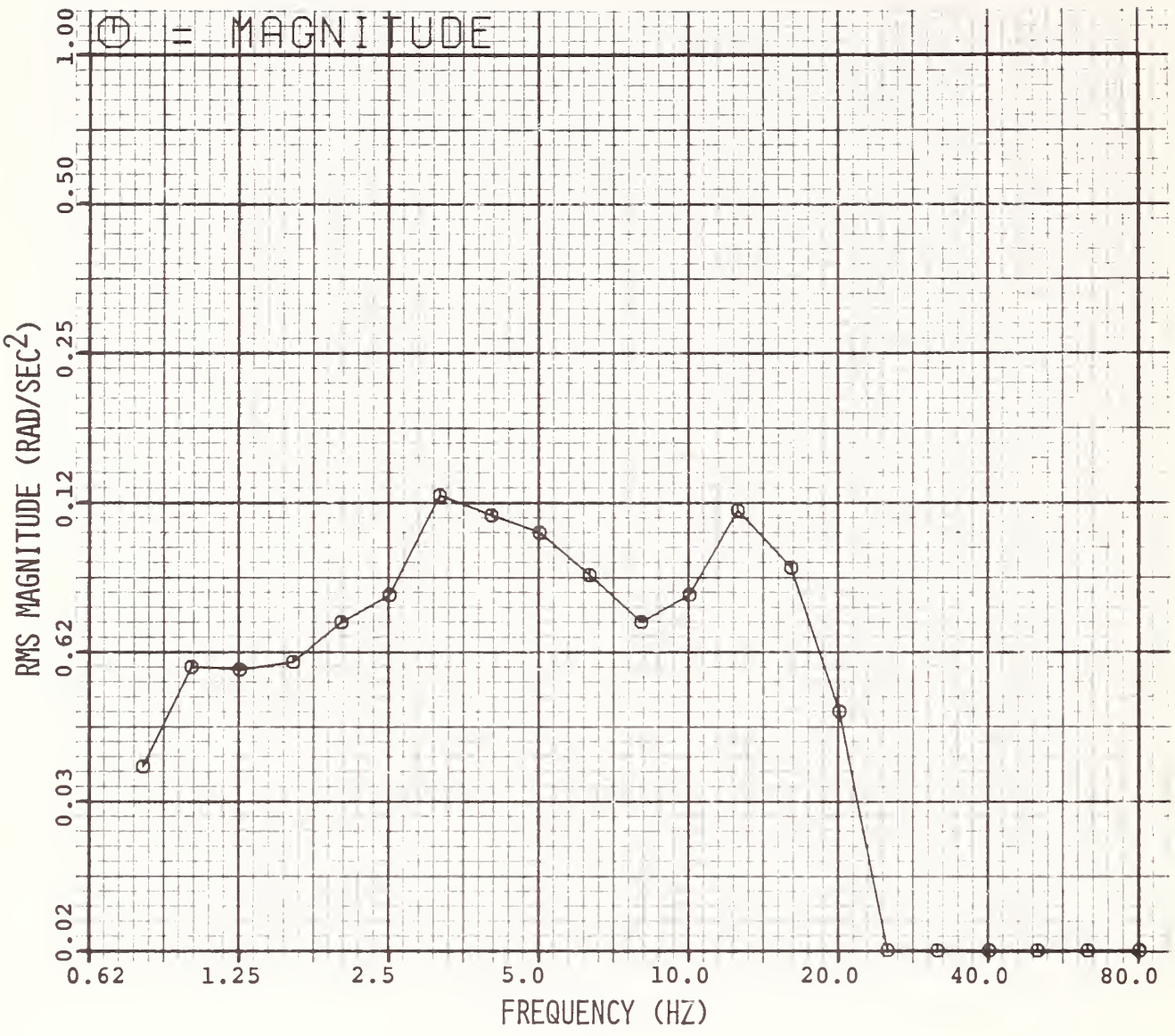


Figure E-11. Nova Vehicle Roll Acceleration, Urban Driving Course.

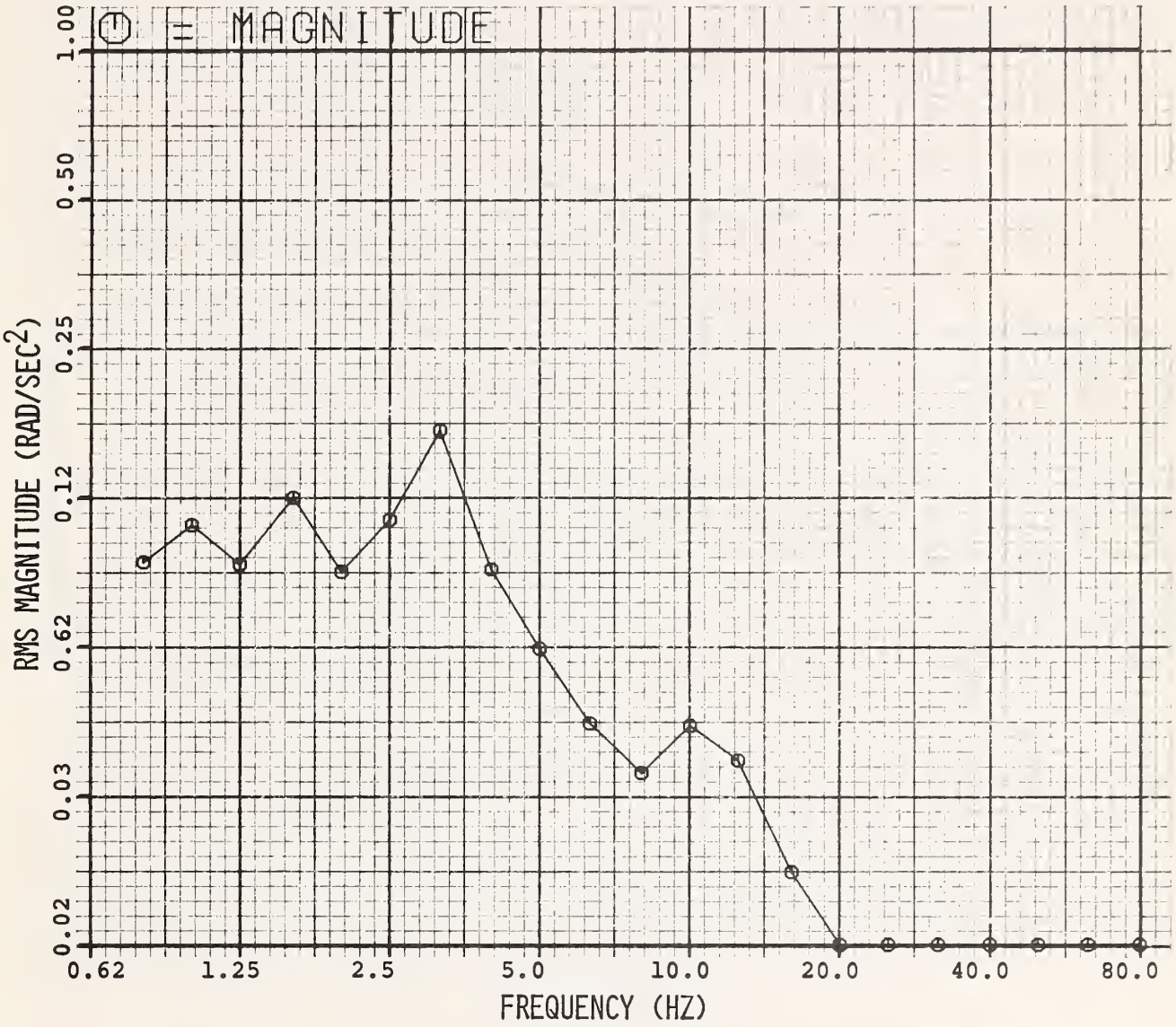


Figure E-12. ASL Vehicle Roll Acceleration, Light Load (Wheelchair Passenger), 5 mph.

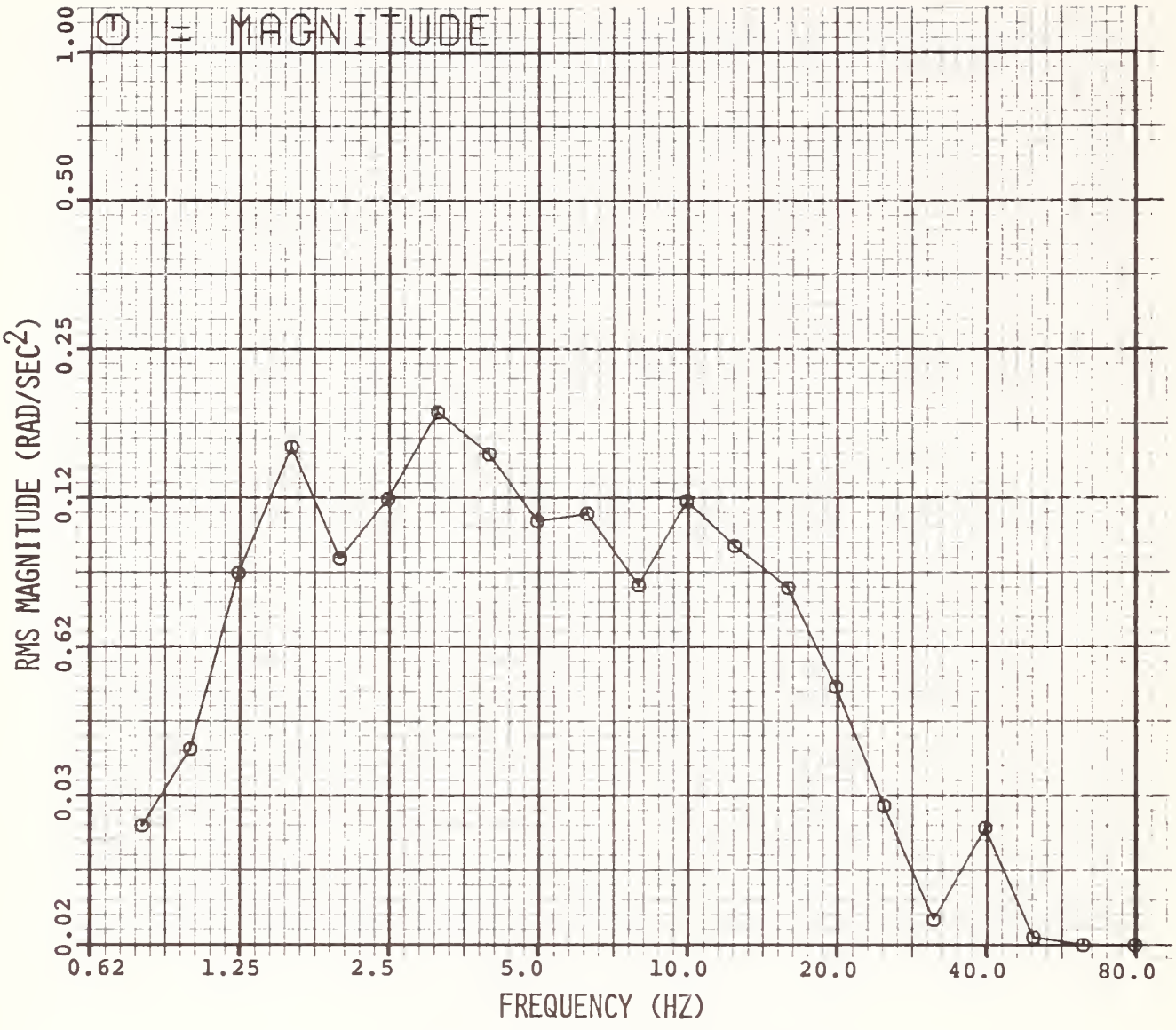


Figure E-13. ASL Vehicle Roll Acceleration, Light Load (Wheelchair Passenger), 10 mph.

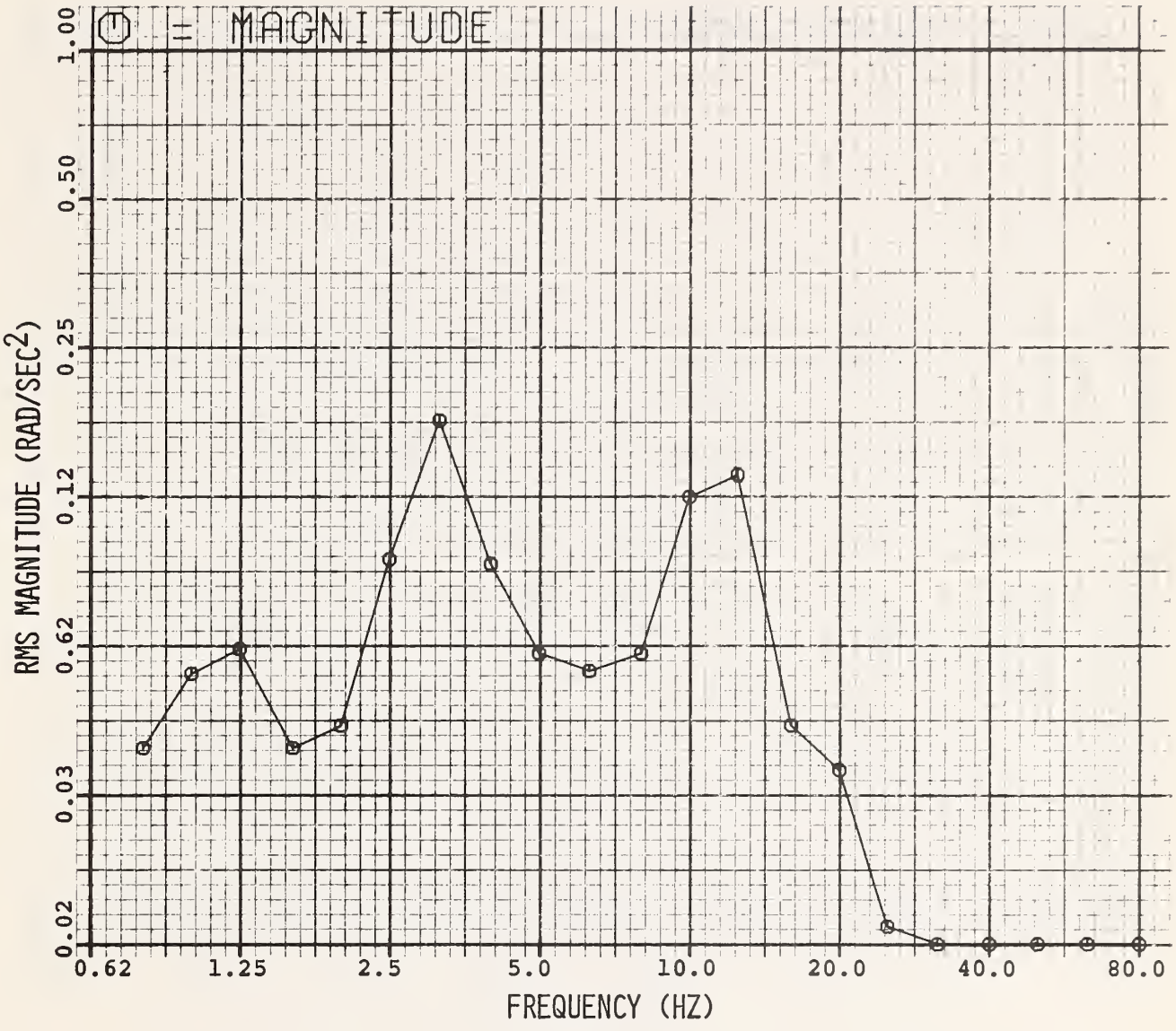


Figure E-14. ASL Vehicle Roll Acceleration, Light Load (Wheelchair Passenger), 20 mph.

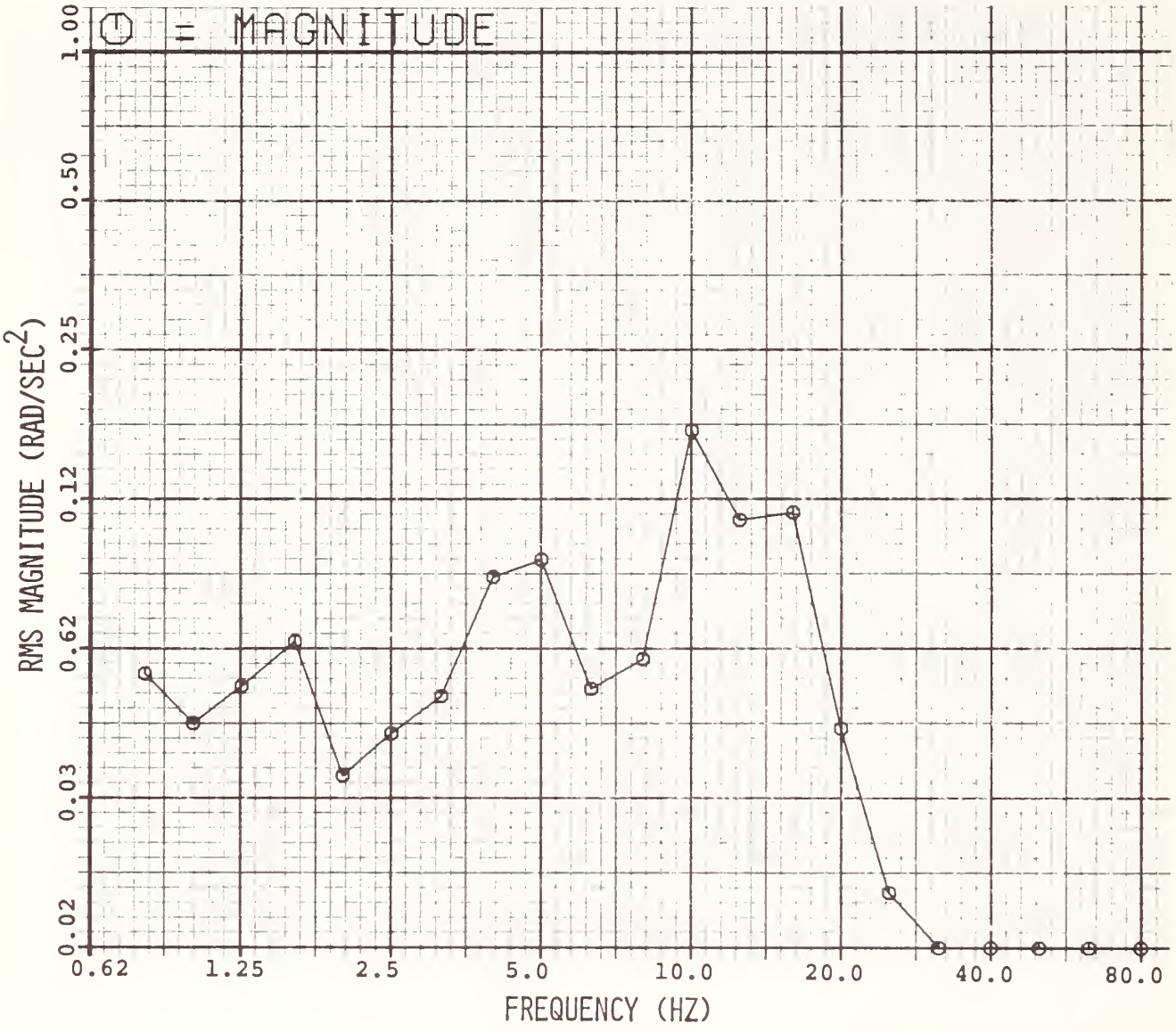


Figure E-15. ASL Vehicle Roll Acceleration, Light Load (Wheelchair Passenger), 30 mph.

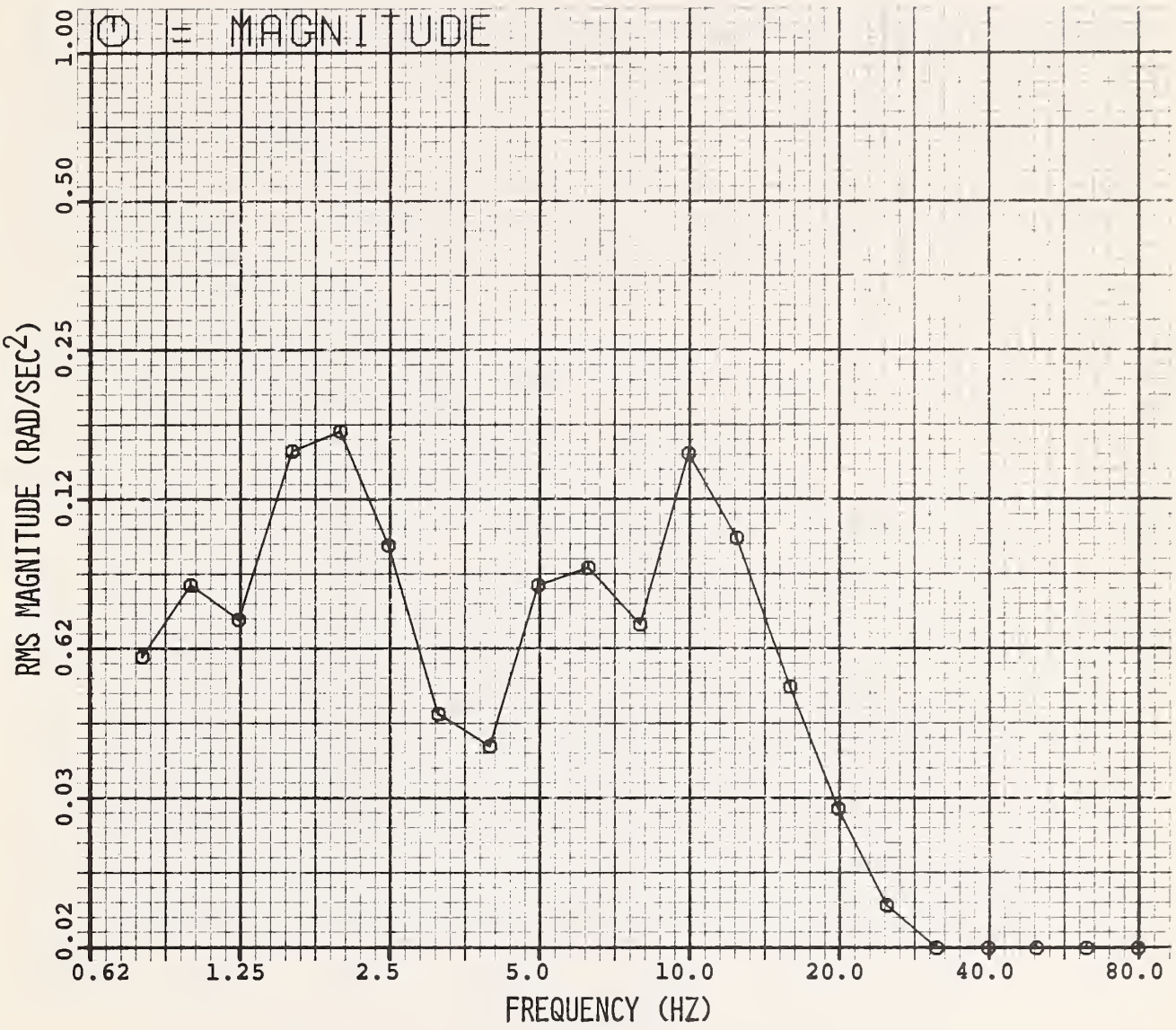


Figure E-16. ASL Vehicle Roll Acceleration, Light Load (Wheelchair Passenger), 40 mph.

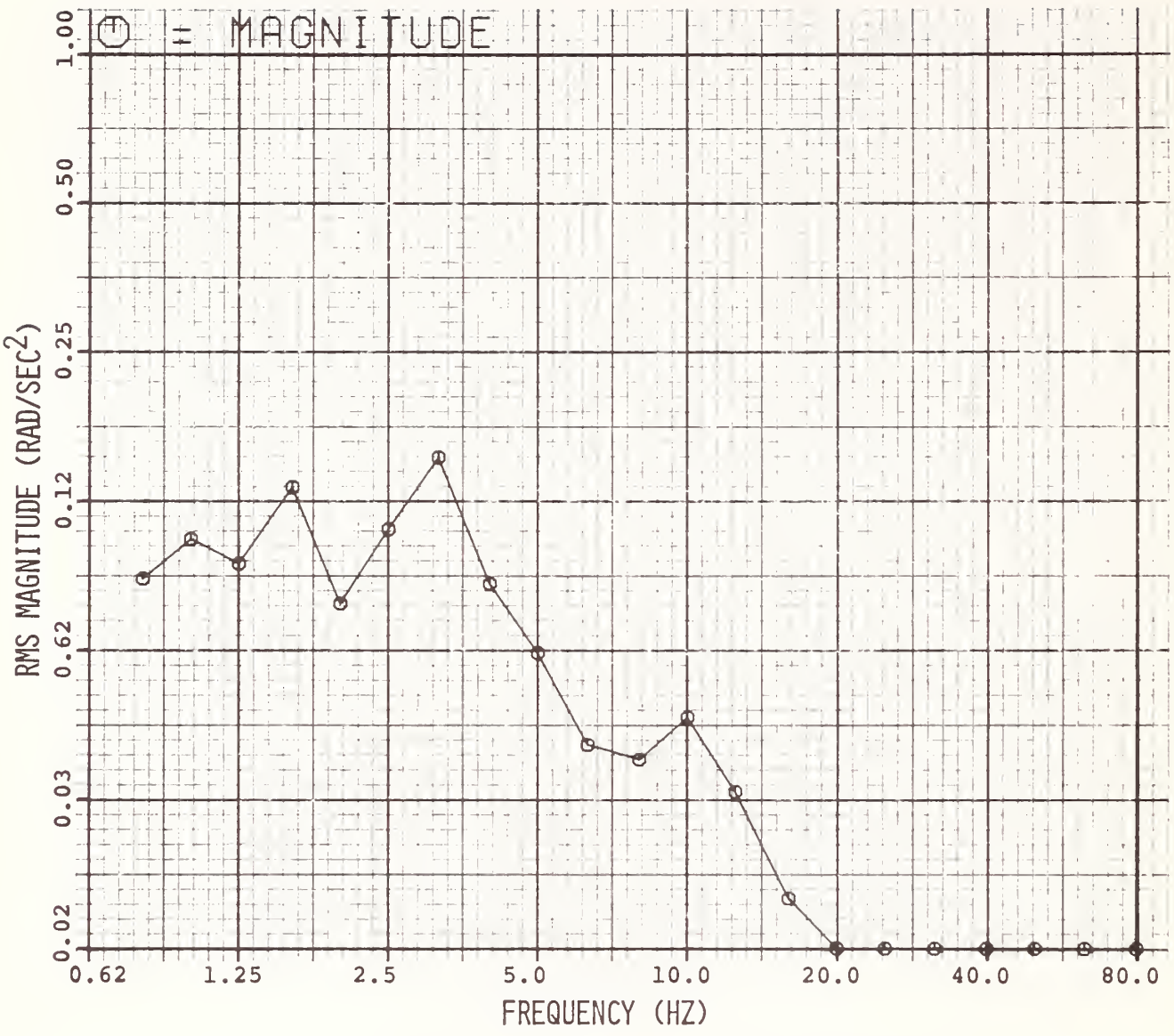


Figure E-17. ASL Vehicle Roll Acceleration, Light Load (Rear Seat Passenger), 5 mph.

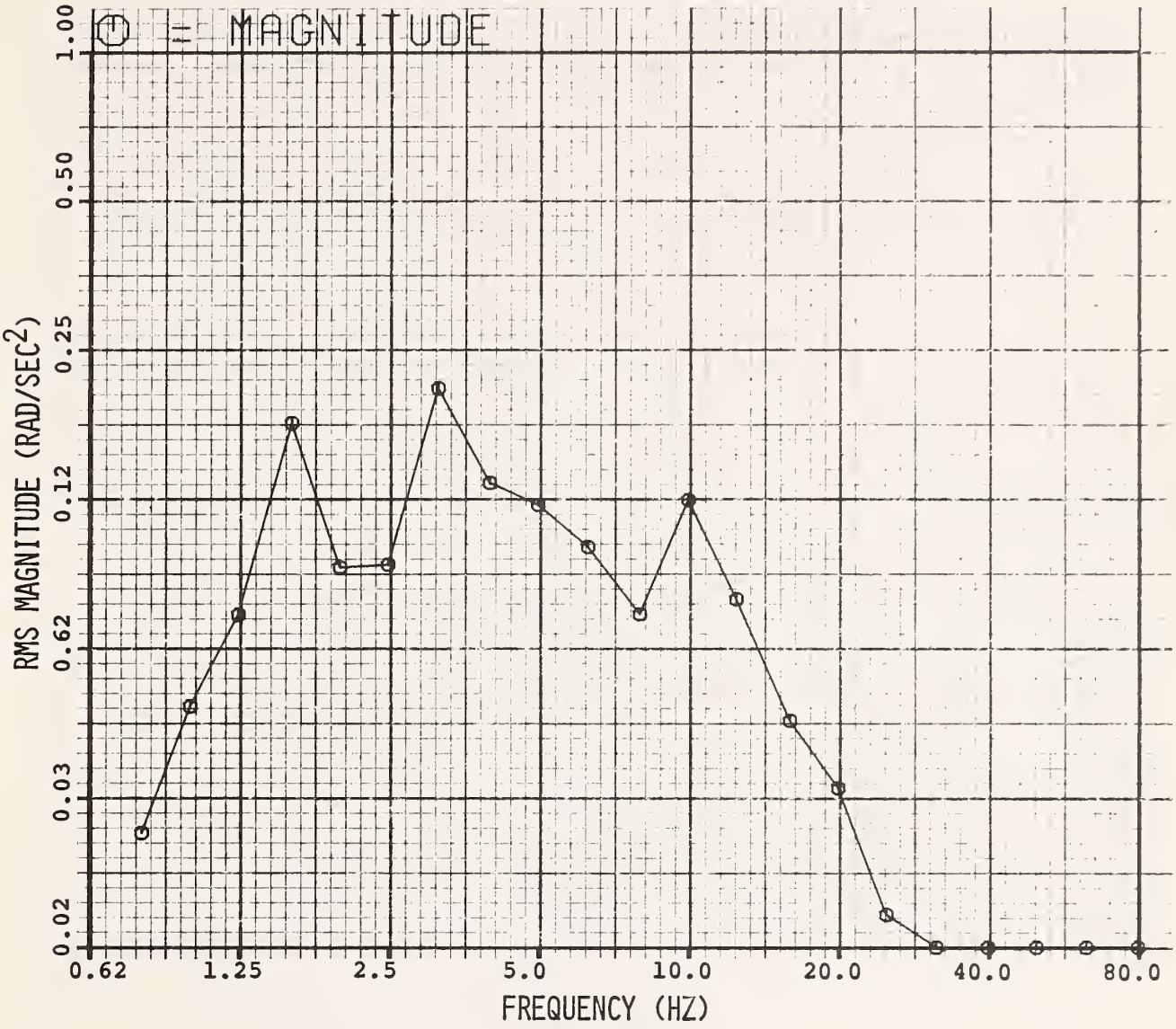


Figure E-18. ASL Vehicle Roll Acceleration, Light Load (Rear Seat Passenger), 10 mph.

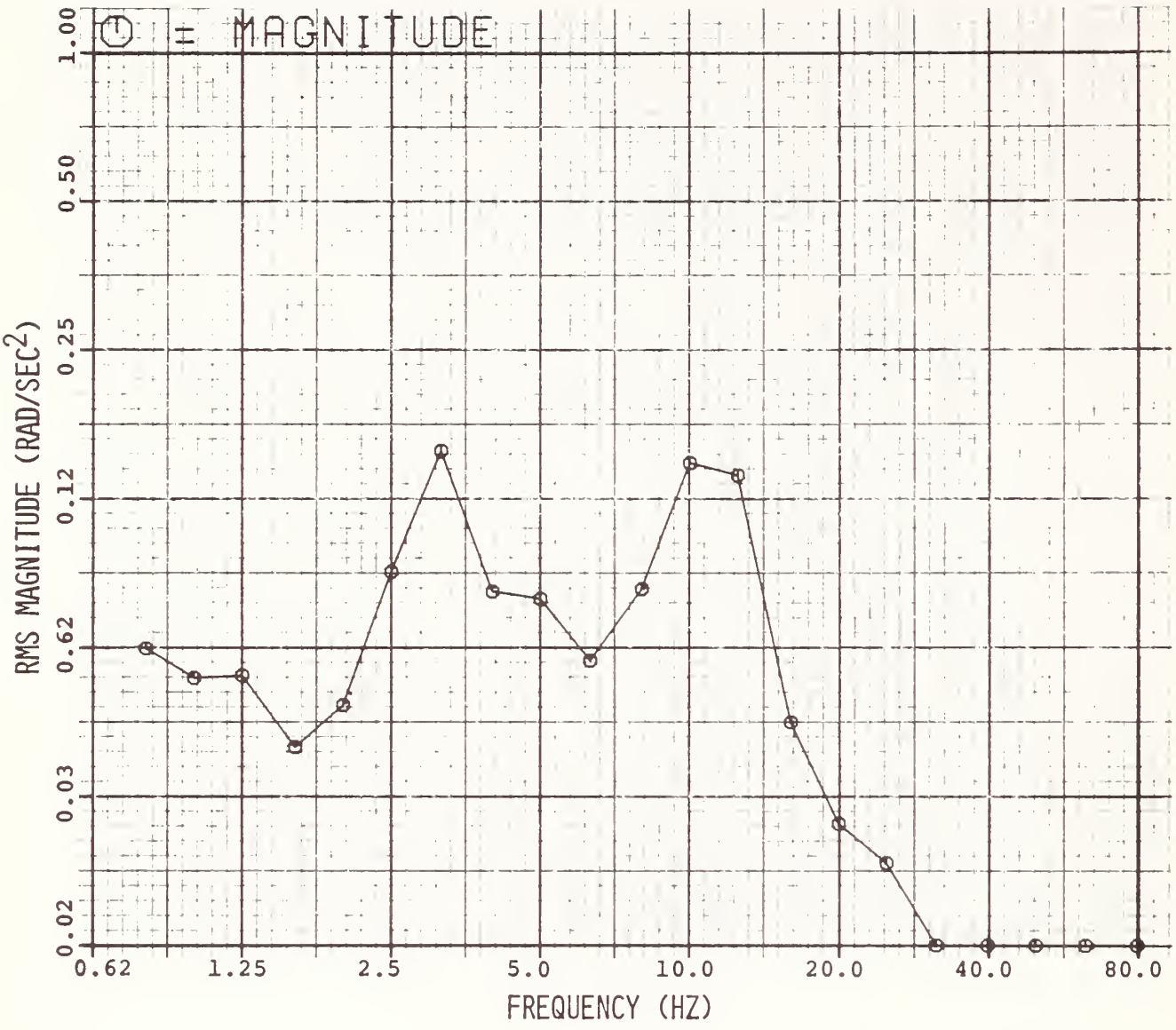


Figure E-19. ASL Vehicle Roll Acceleration, Light Load (Rear Seat Passenger), 20 mph.

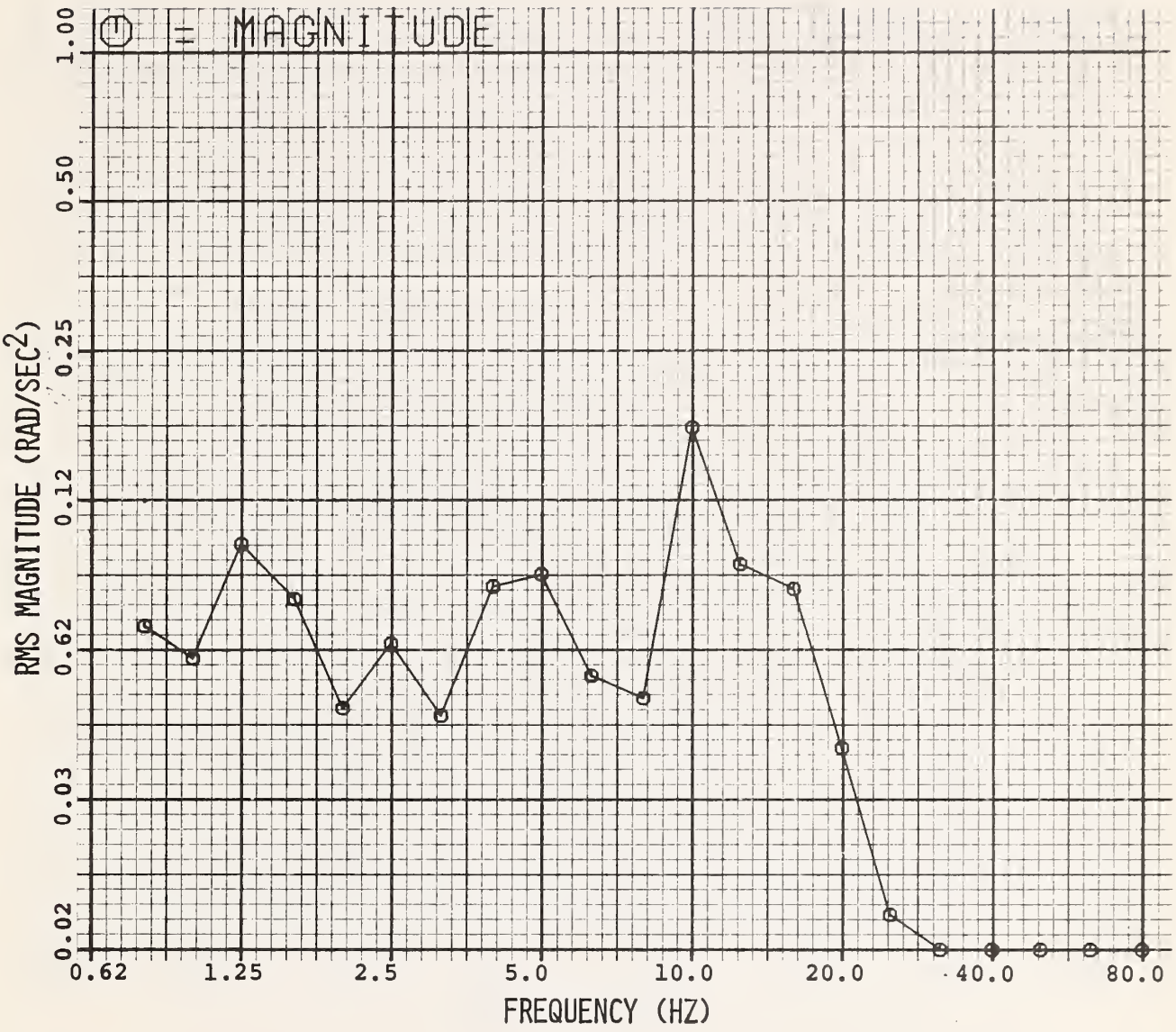


Figure E-20. ASL Vehicle Roll Acceleration, Light Load (Rear Seat Passenger), 30 mph.

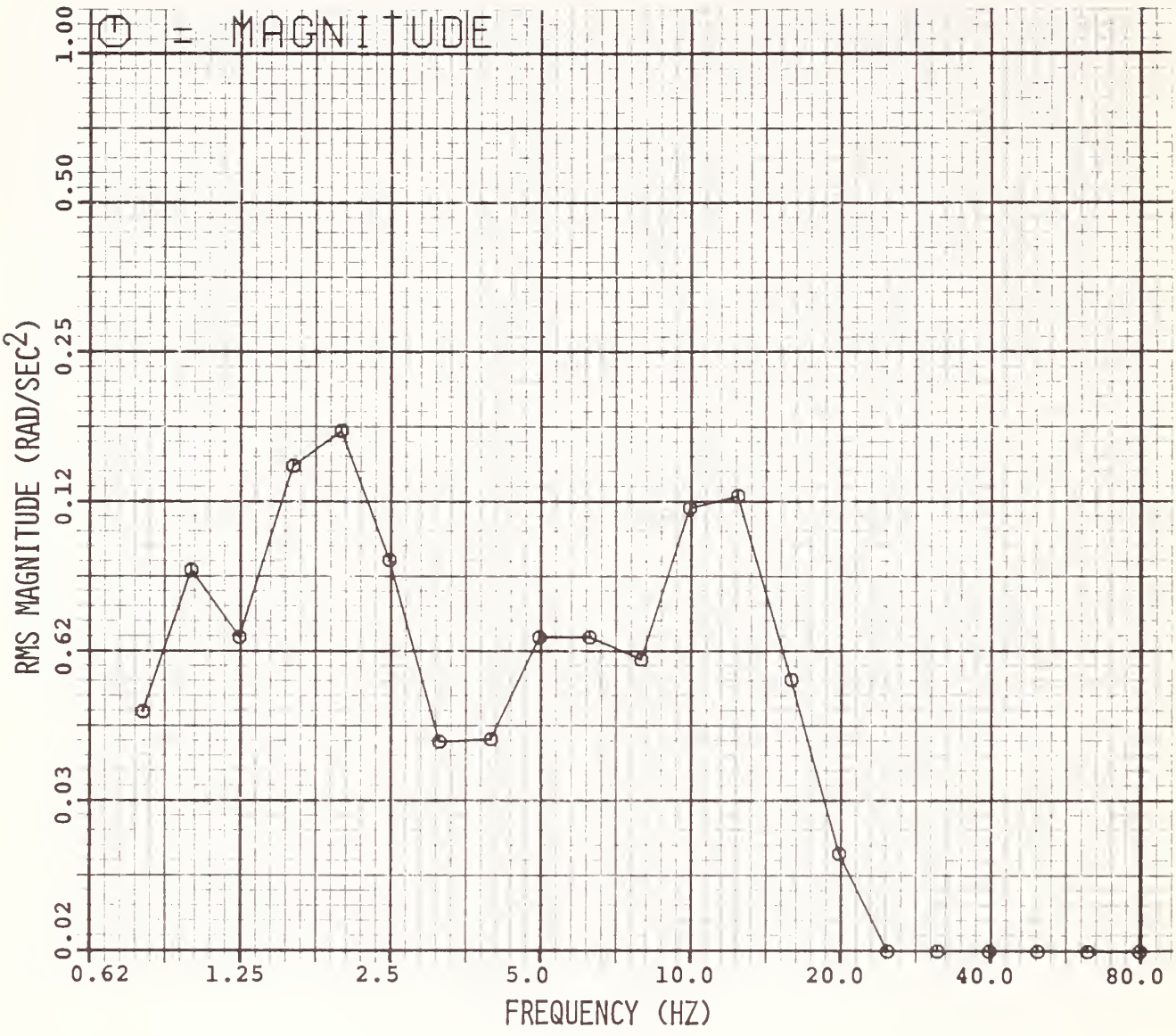


Figure E-21. ASL Vehicle Roll Acceleration, Light Load (Rear Seat Passenger), 40 mph.

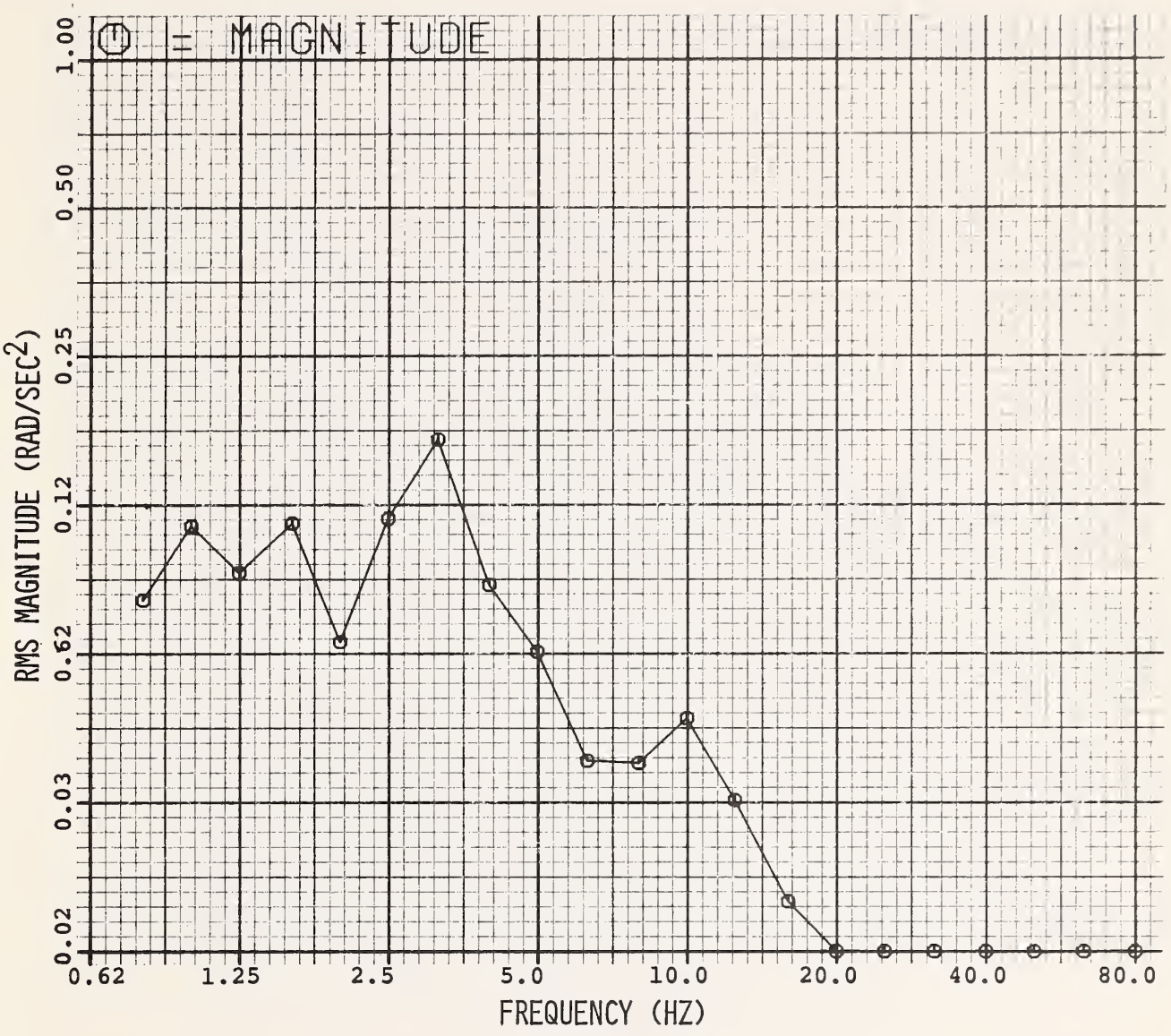


Figure E-22. ASL Vehicle Roll Acceleration, Heavy Load, 5 mph.

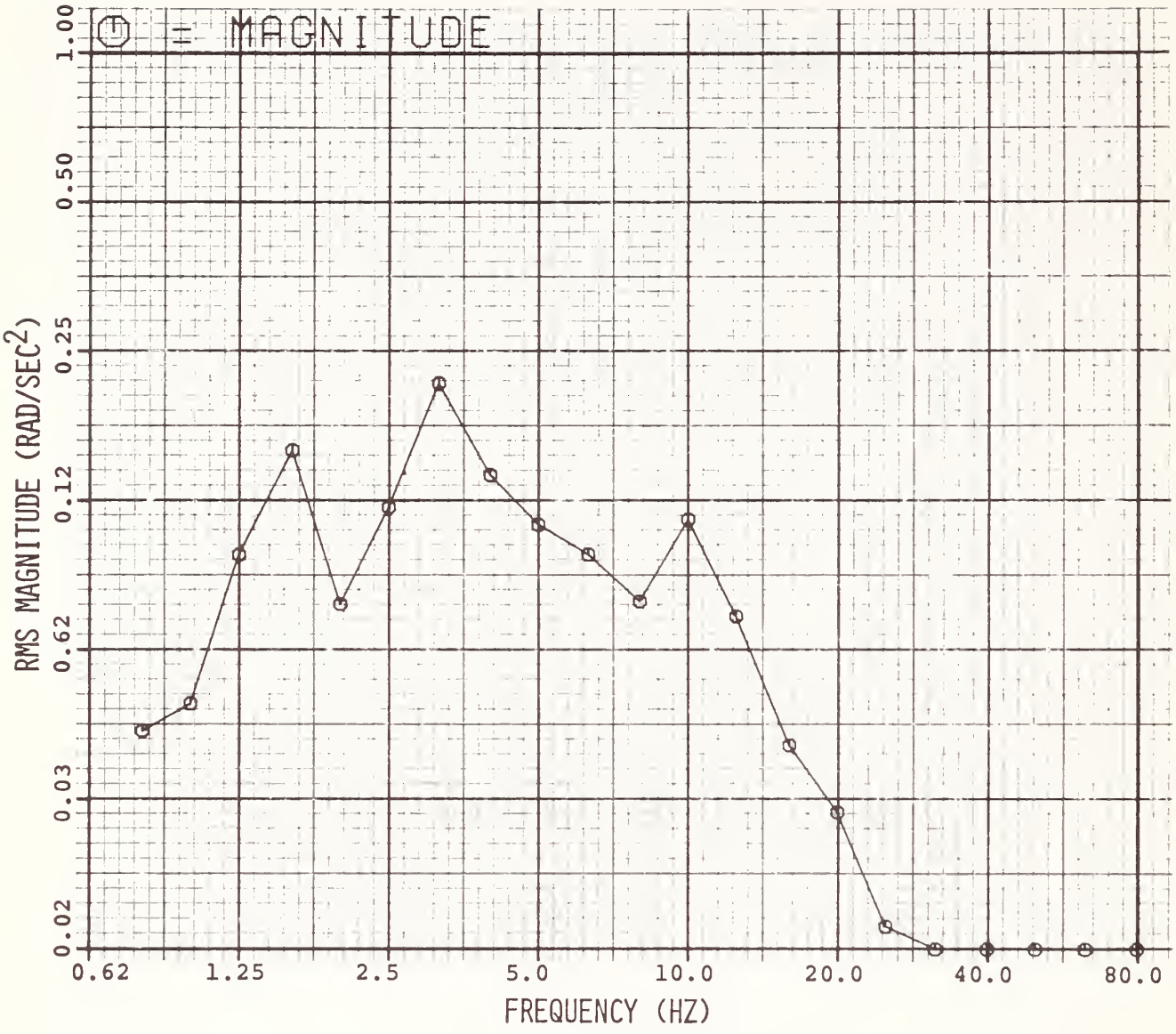


Figure E-23. ASL Vehicle Roll Acceleration, Heavy Load, 10 mph.

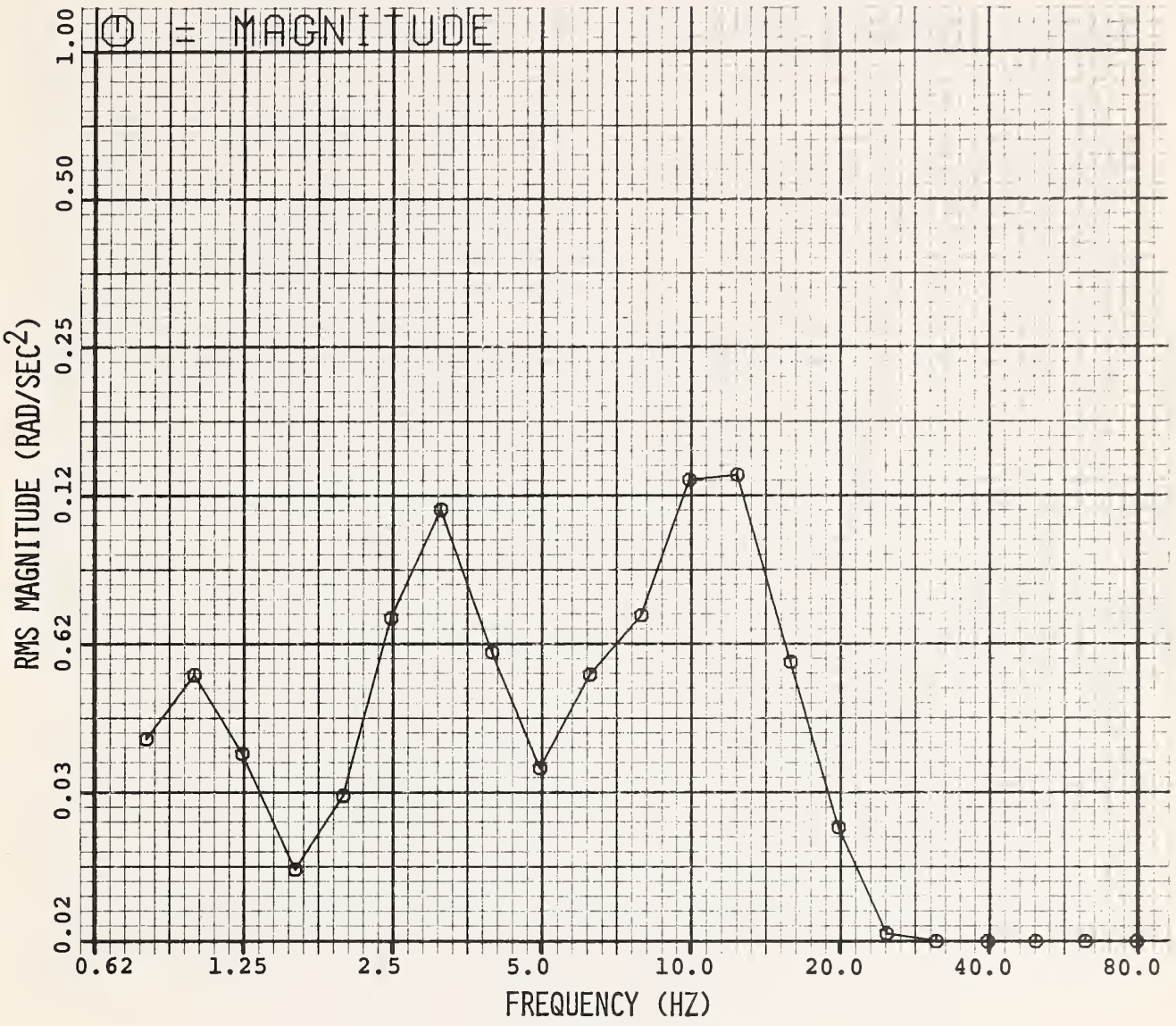


Figure E-24. ASL Vehicle Roll Acceleration, Heavy Load, 20 mph.

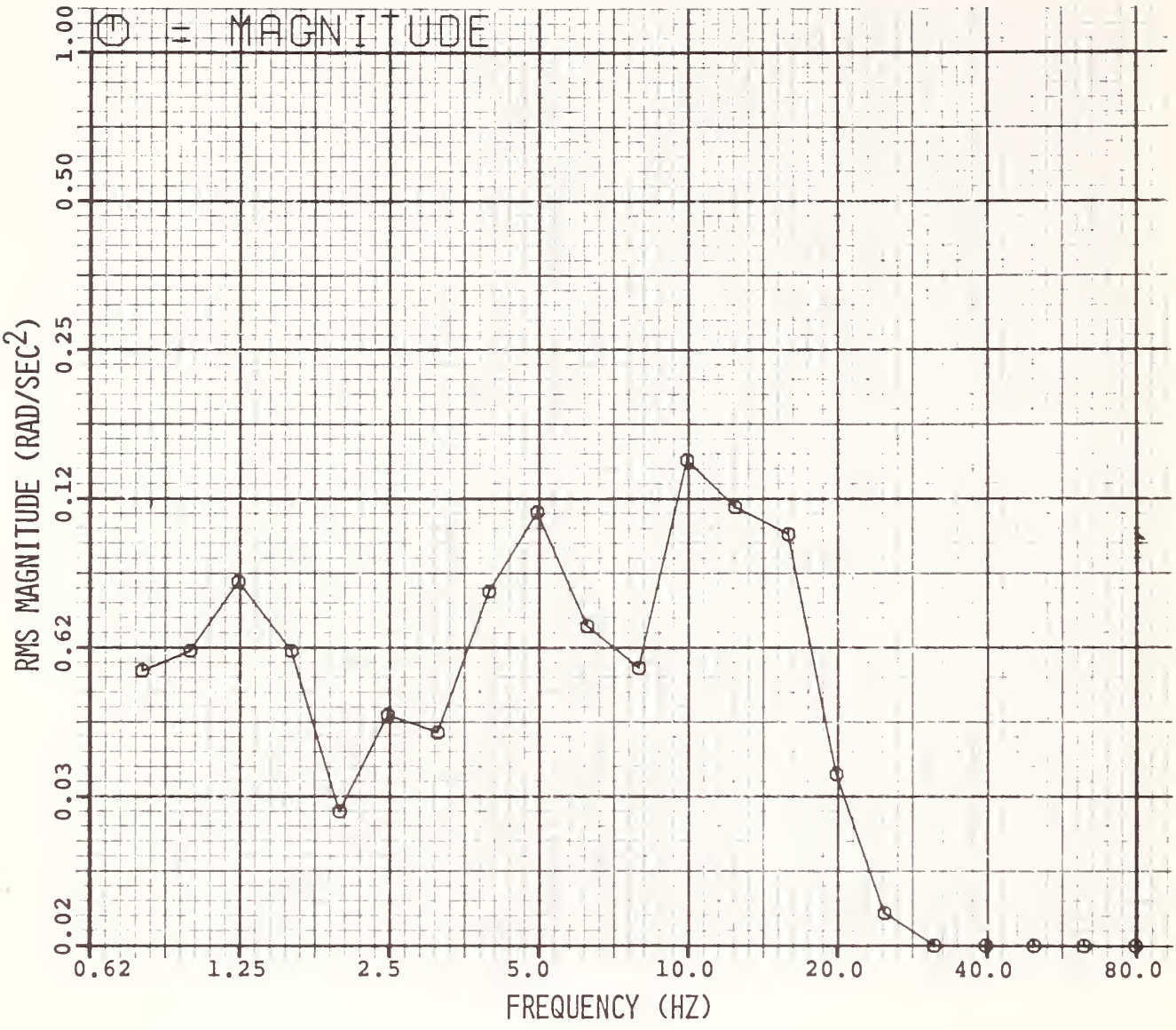


Figure E-25. ASL Vehicle Roll Acceleration, Heavy Load, 30 mph.

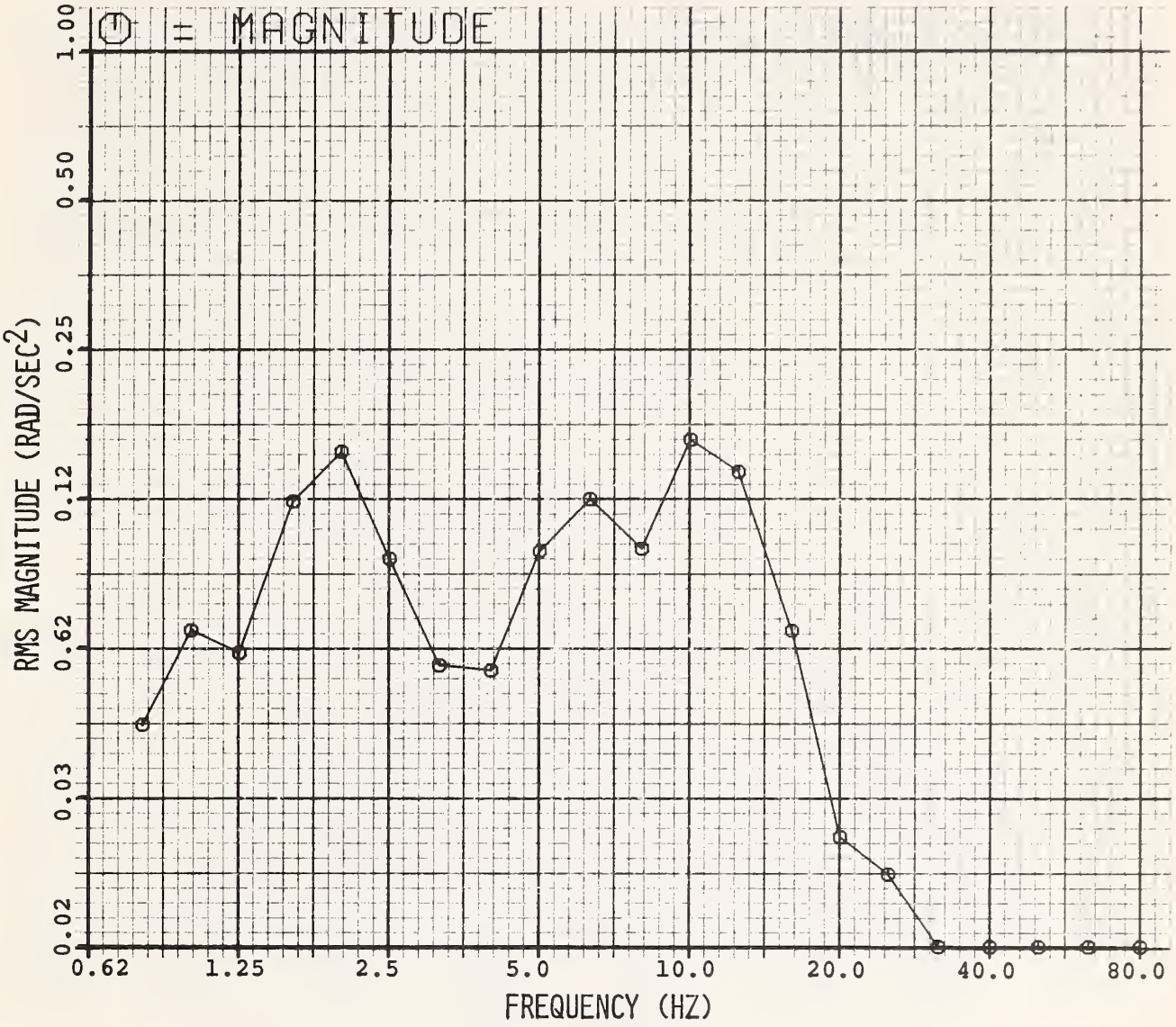


Figure E-26. ASL Vehicle Roll Acceleration, Heavy Load, 40 mph.

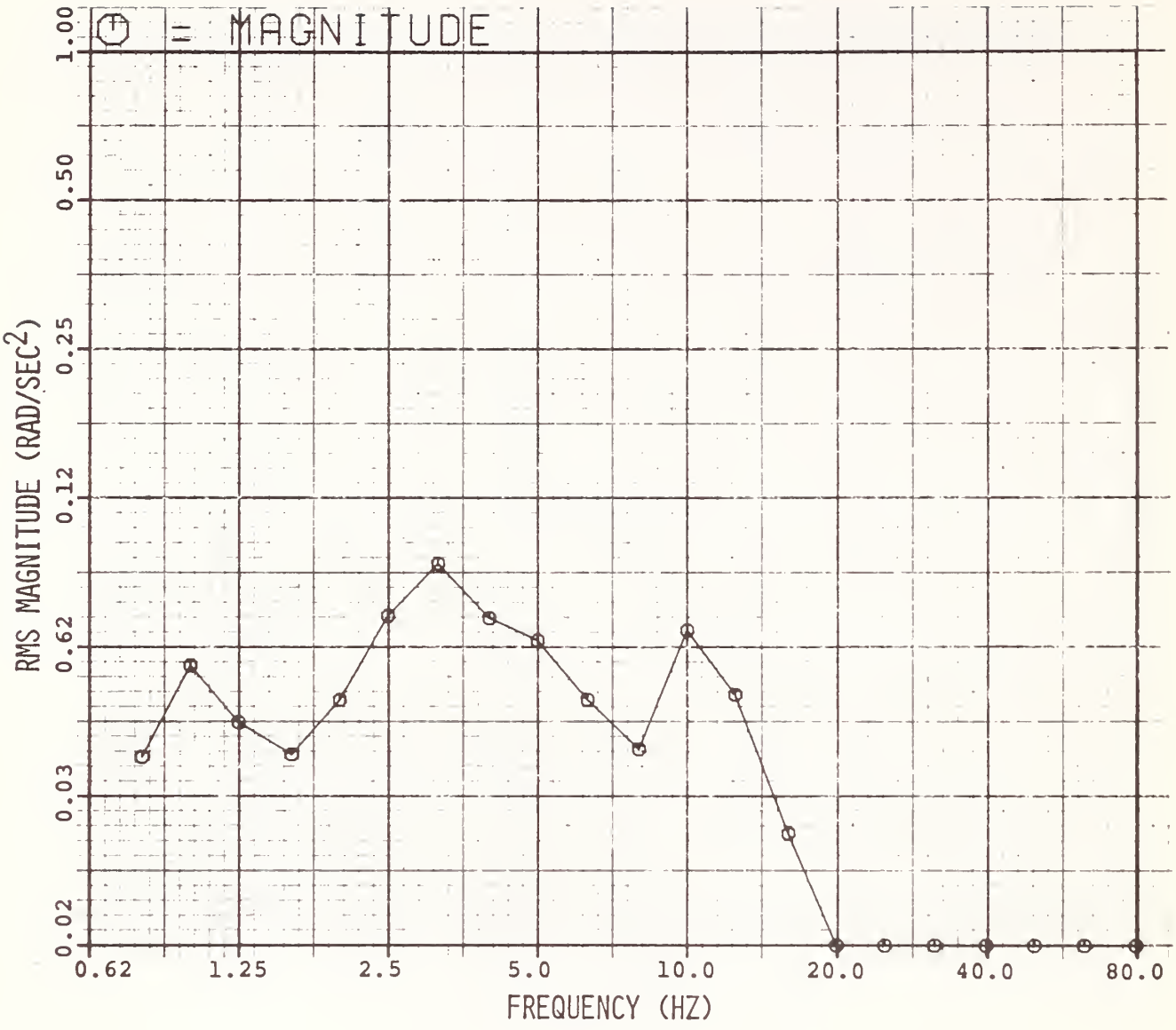


Figure E-27. ASL Vehicle Roll Acceleration, Urban Driving Course.

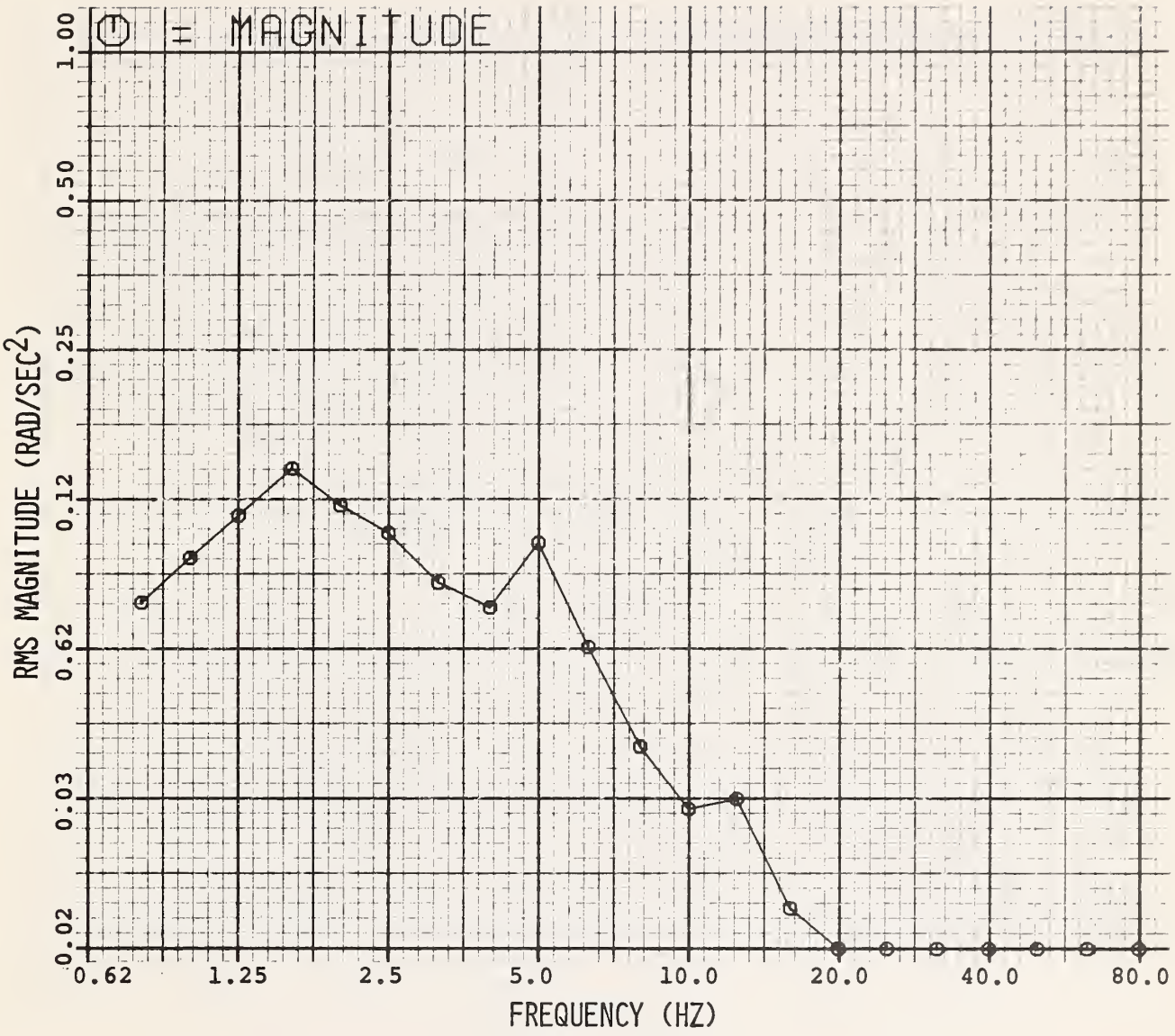


Figure E-28. Dutcher Vehicle Roll Acceleration, Light Load (Wheelchair Passenger), 5 mph.

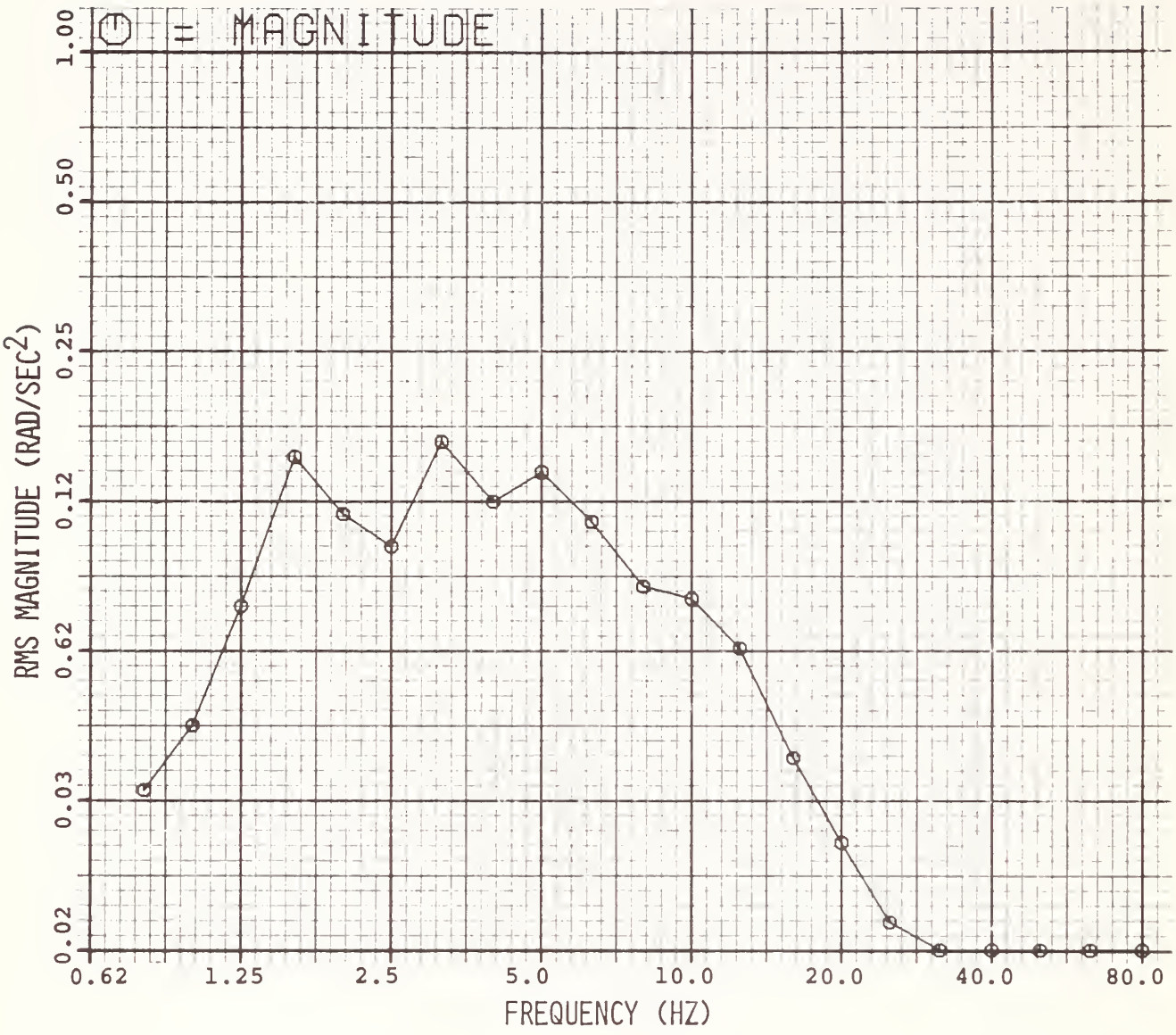


Figure E-29. Dutcher Vehicle Roll Acceleration, Light Load (Wheelchair Passenger), 10 mph.

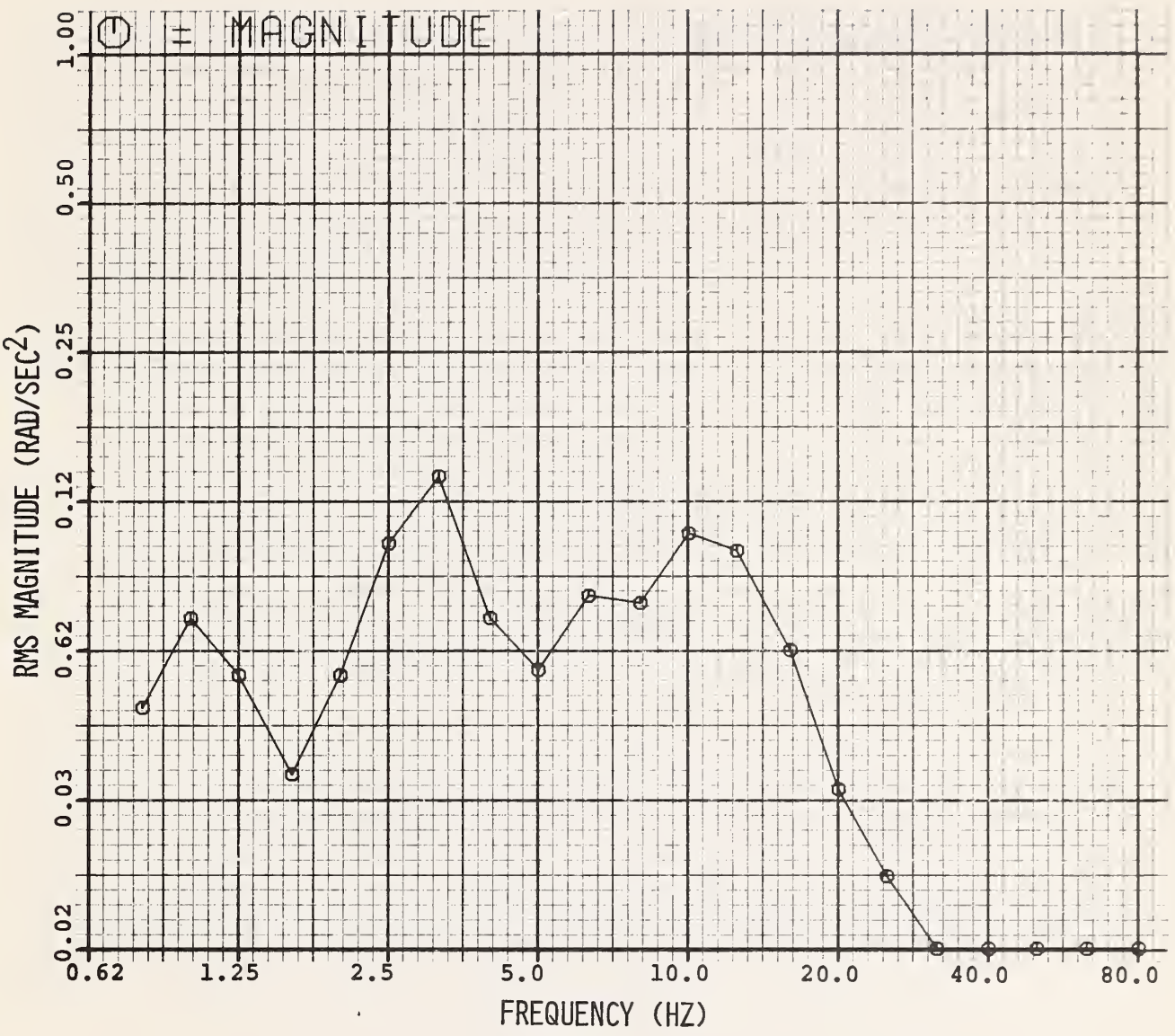


Figure E-30. Dutcher Vehicle Roll Acceleration, Light Load (Wheelchair Passenger), 20 mph.

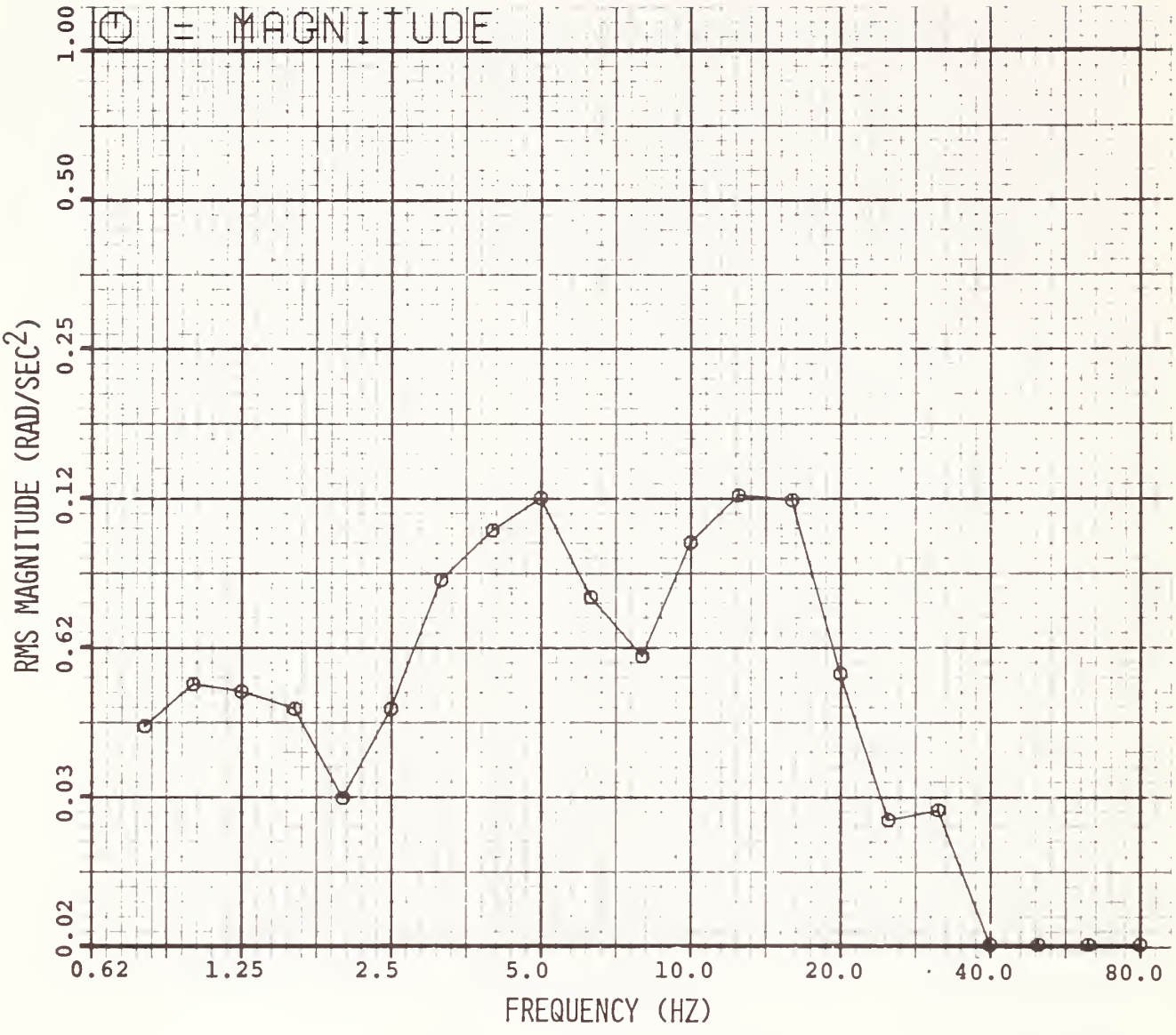


Figure E-31. Dutcher Vehicle Roll Acceleration, Light Load (Wheelchair Passenger), 30 mph.

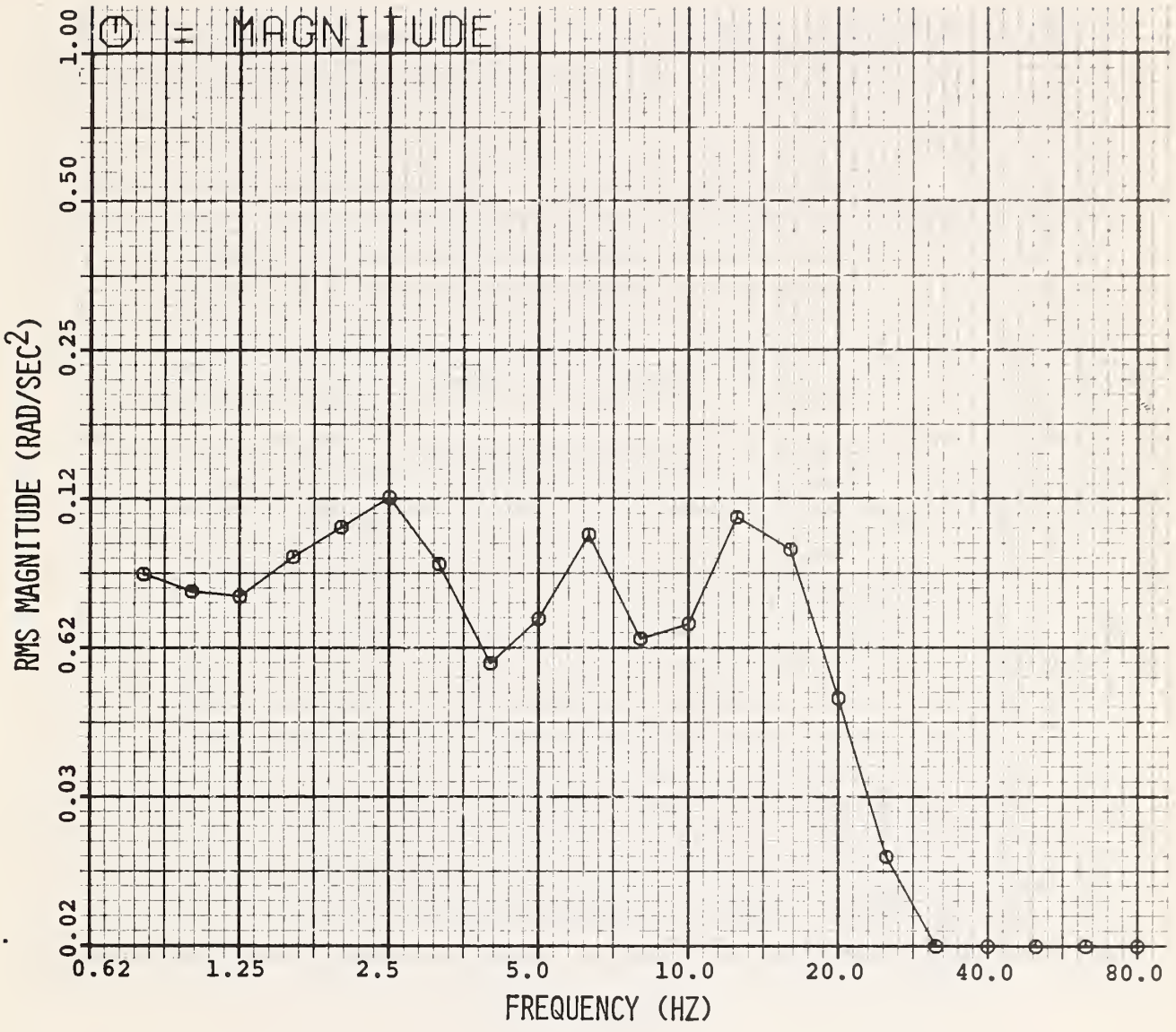


Figure E-32. Dutcher Vehicle Roll Acceleration, Light Load (Wheelchair Passenger), 40 mph.

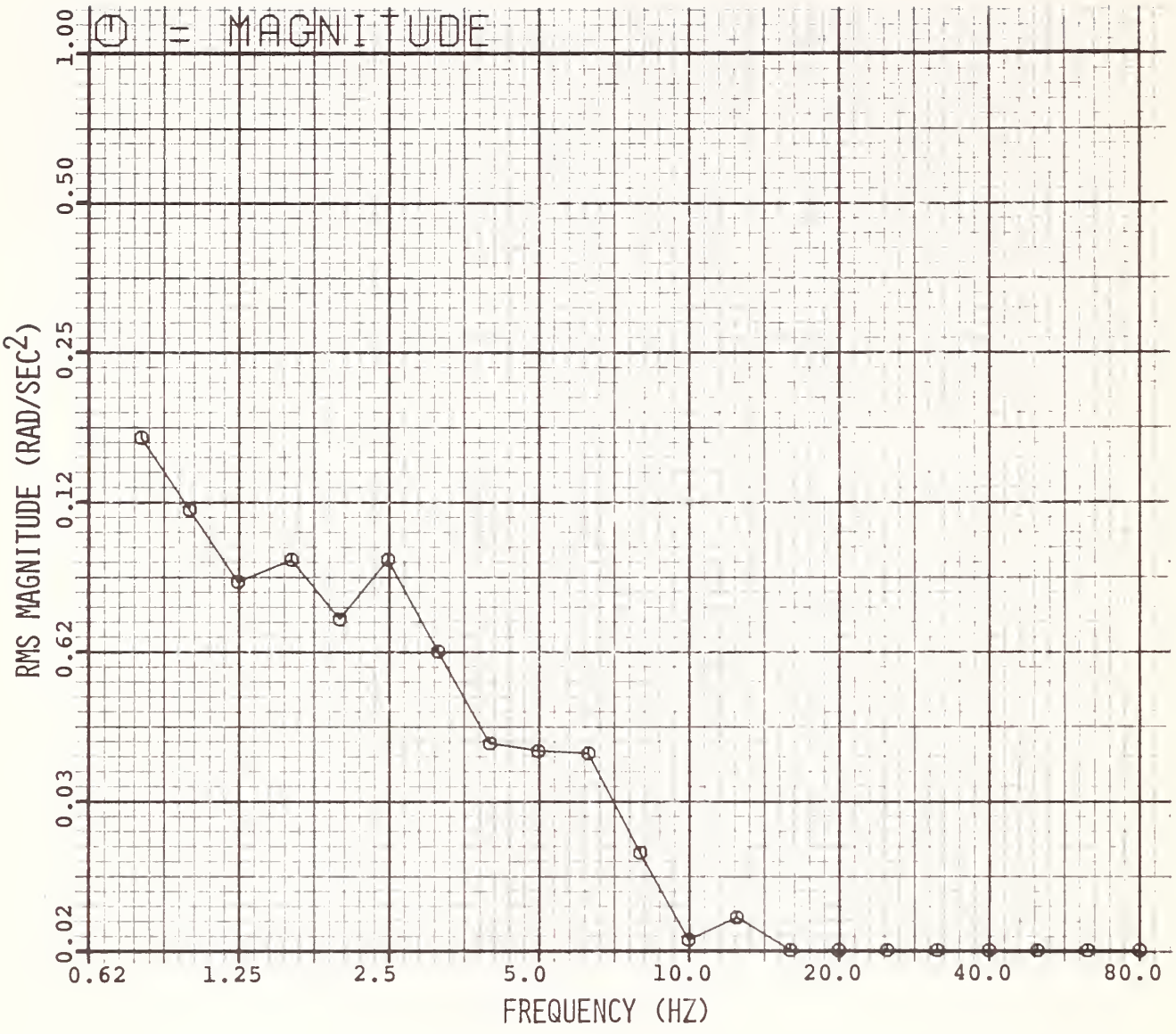


Figure E-33. Dutcher Vehicle Roll Acceleration, Light Load (Rear Seat Passenger), 5 mph.

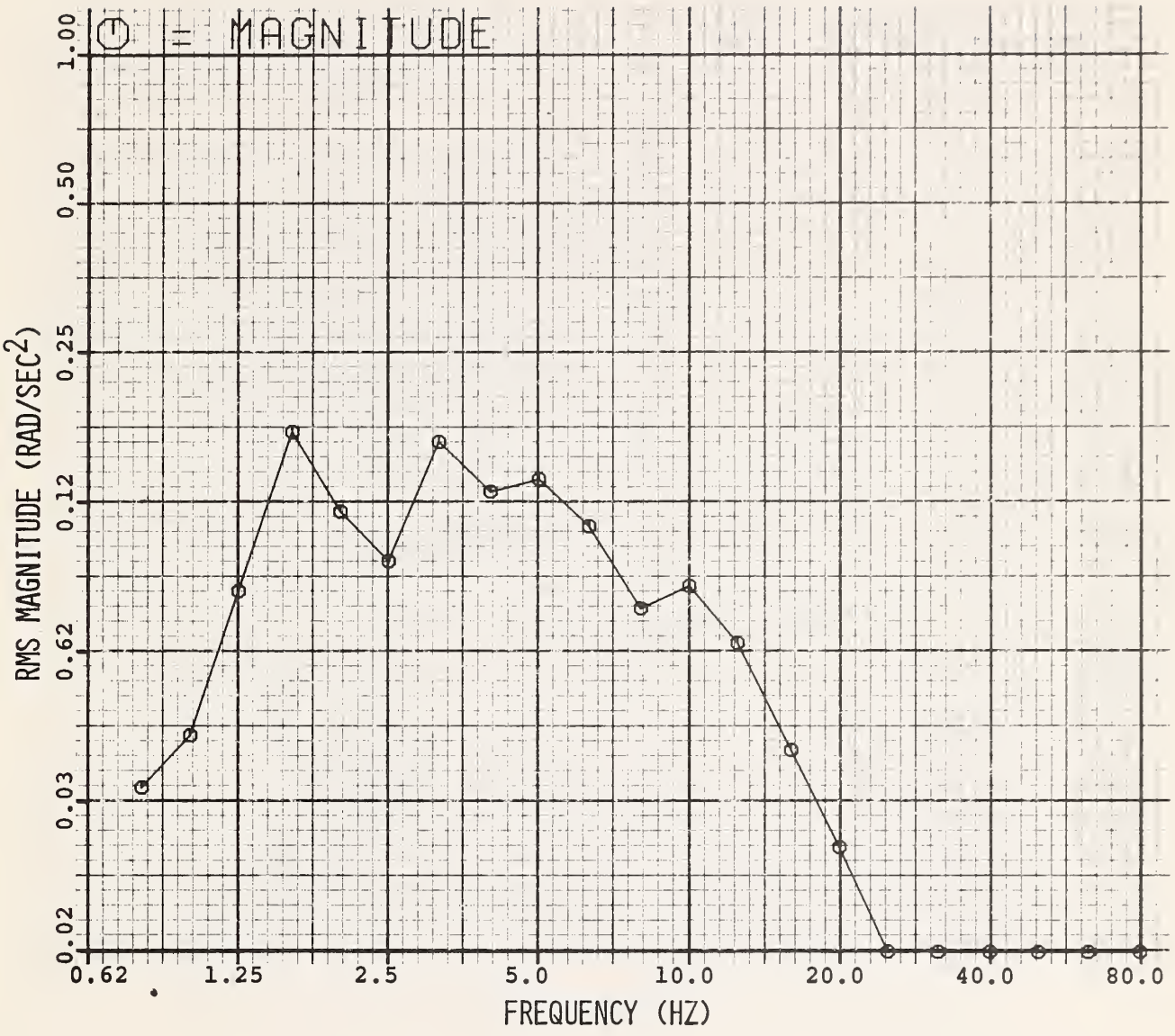


Figure E-34. Dutcher Vehicle Roll Acceleration, Light Load (Rear Seat Passenger), 10 mph.

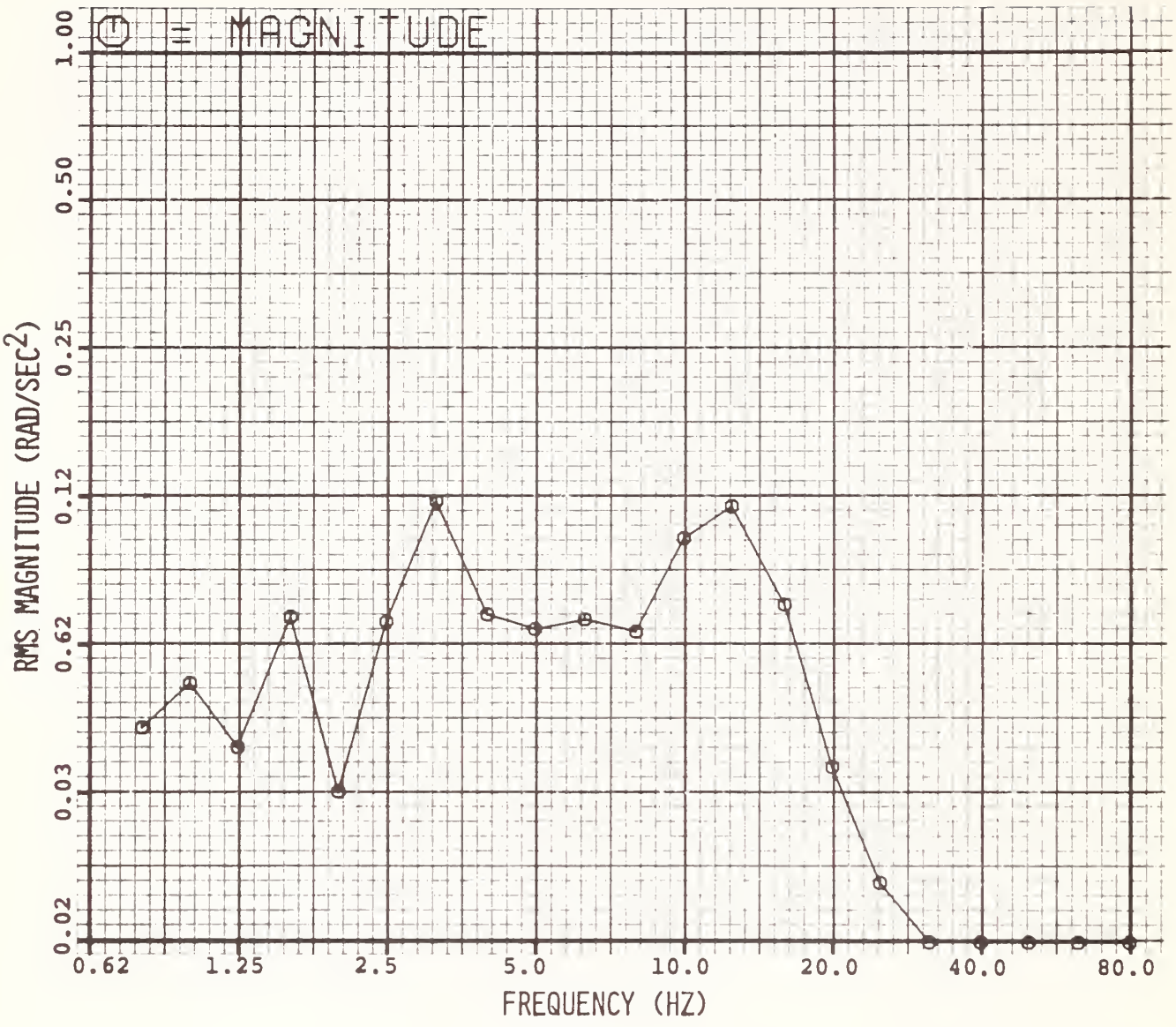


Figure E-35. Dutcher Vehicle Roll Acceleration, Light Load (Rear Seat Passenger), 20 mph.

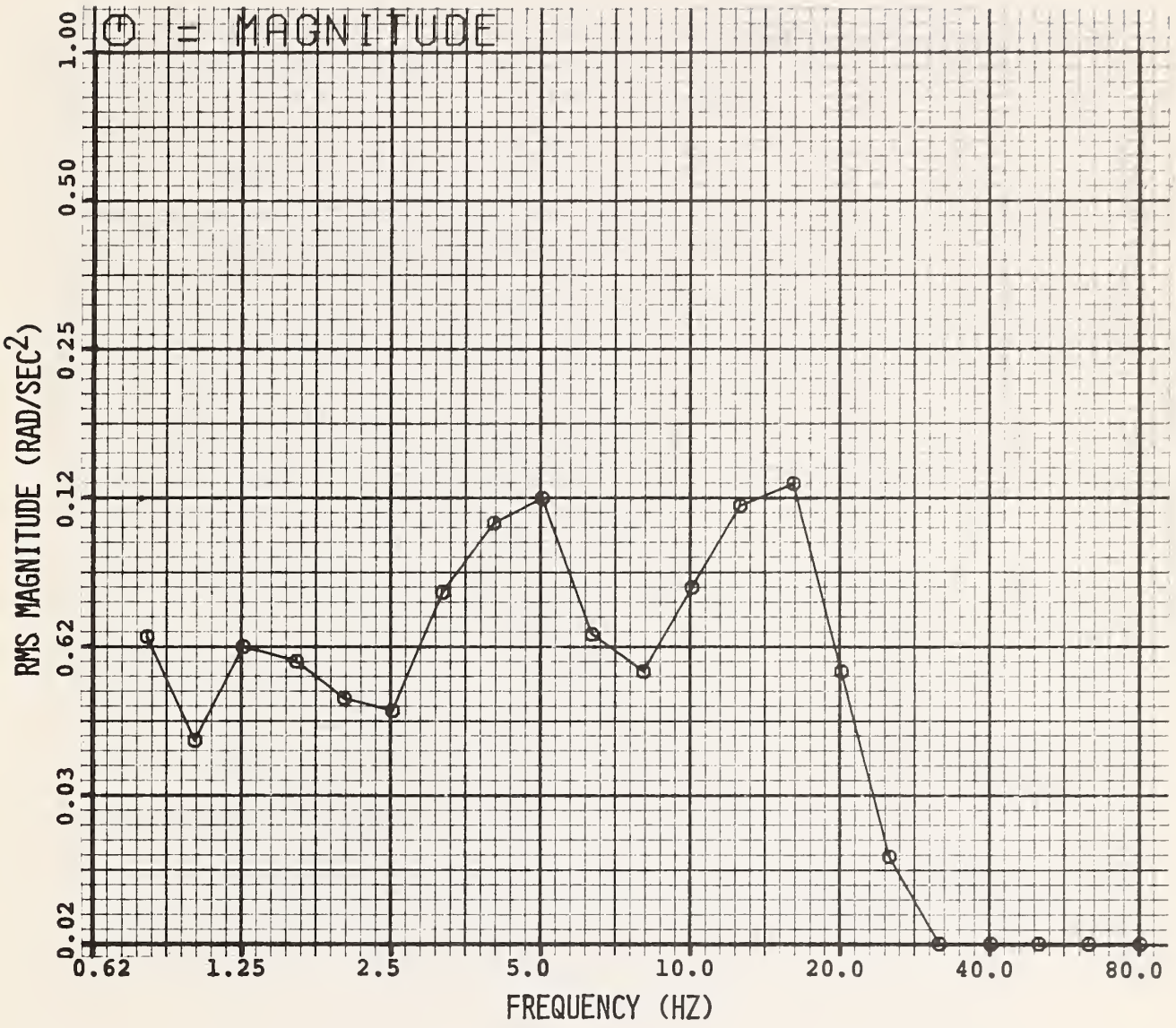


Figure E-36. Dutcher Vehicle Roll Acceleration, Light Load (Rear Seat Passenger), 30 mph.

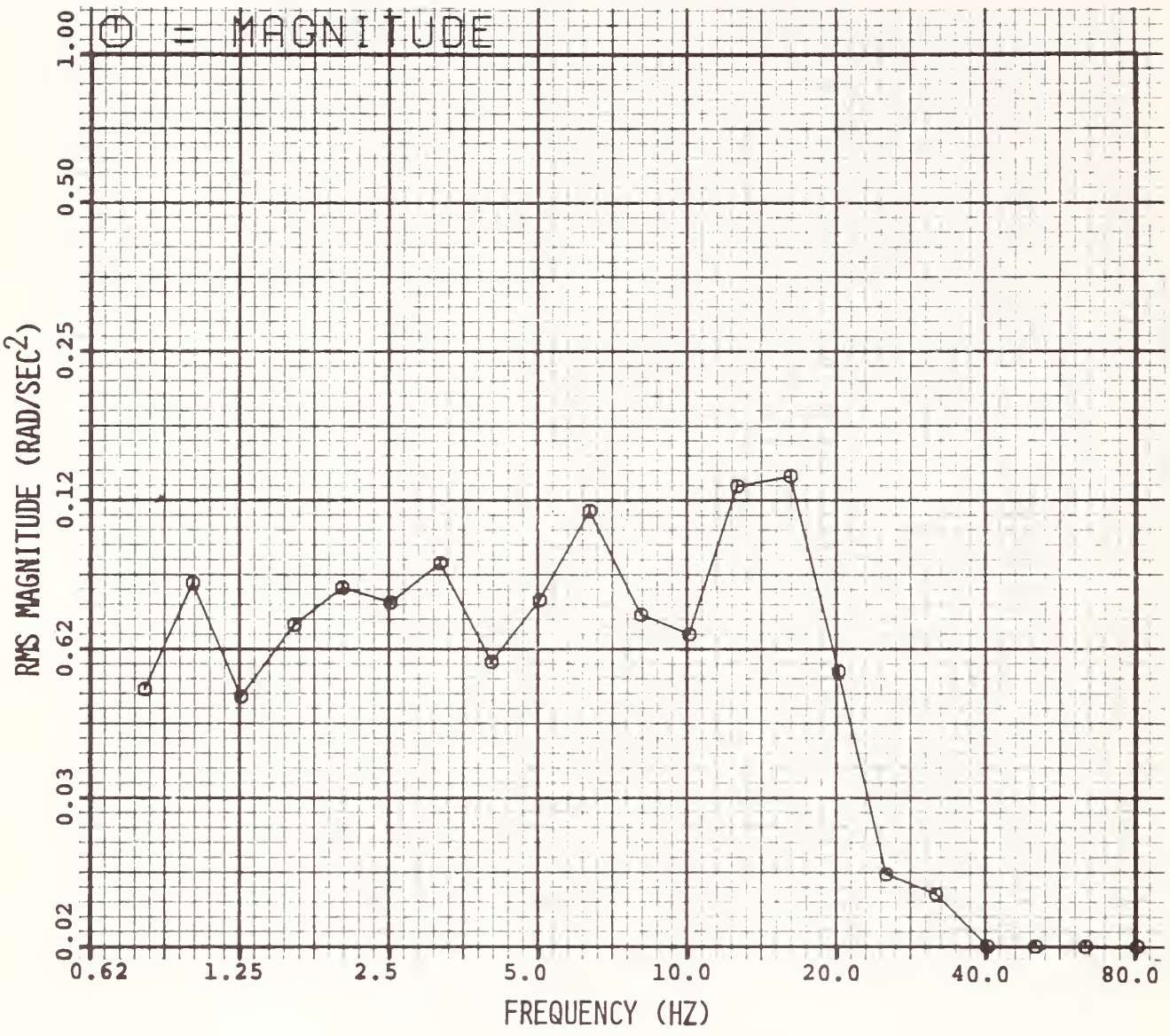


Figure E-37. Dutcher Vehicle Roll Acceleration, Light Load (Rear Seat Passenger), 40 mph.

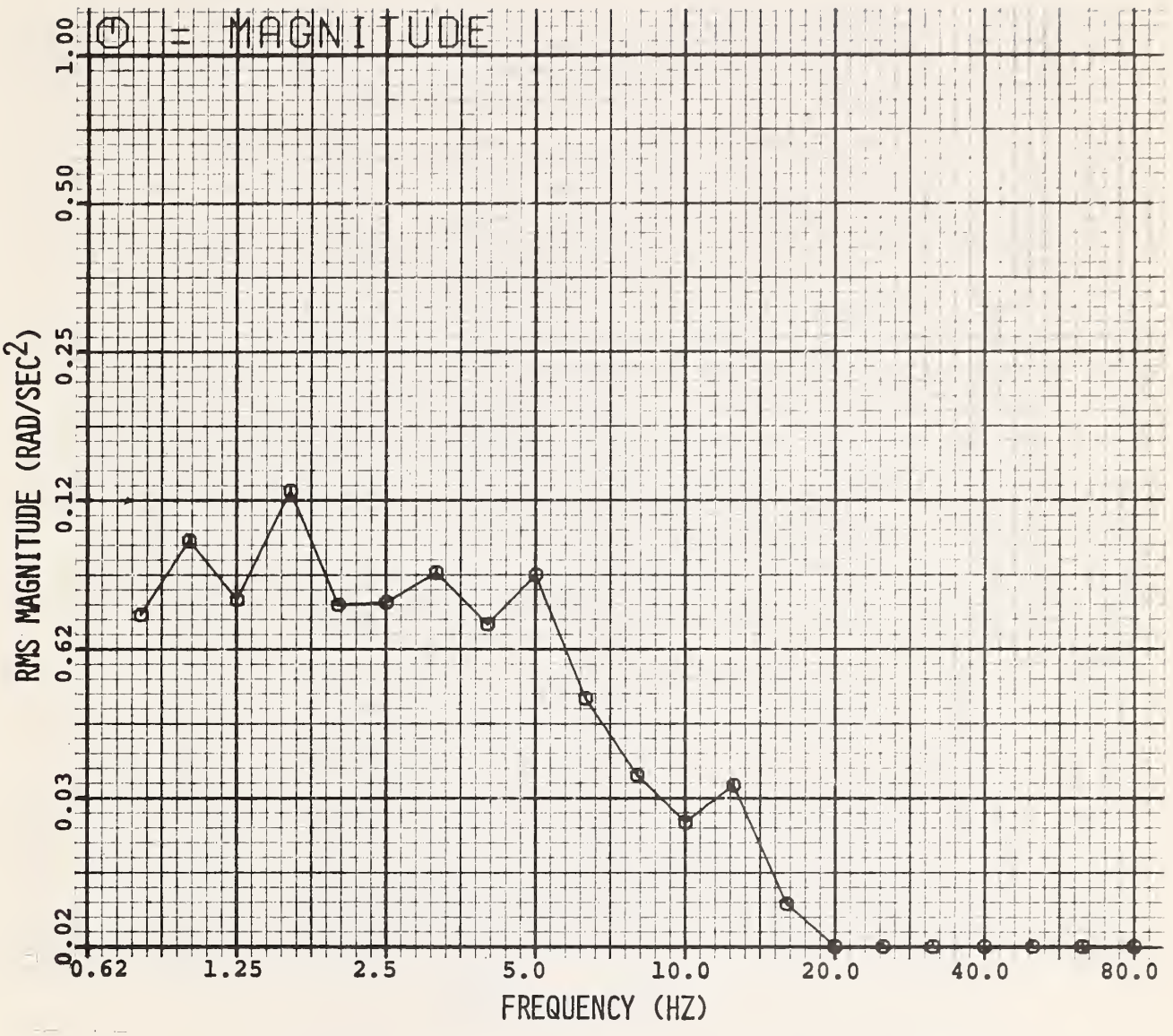


Figure E-38. Dutcher Vehicle Roll Acceleration, Heavy Load, 5 mph.

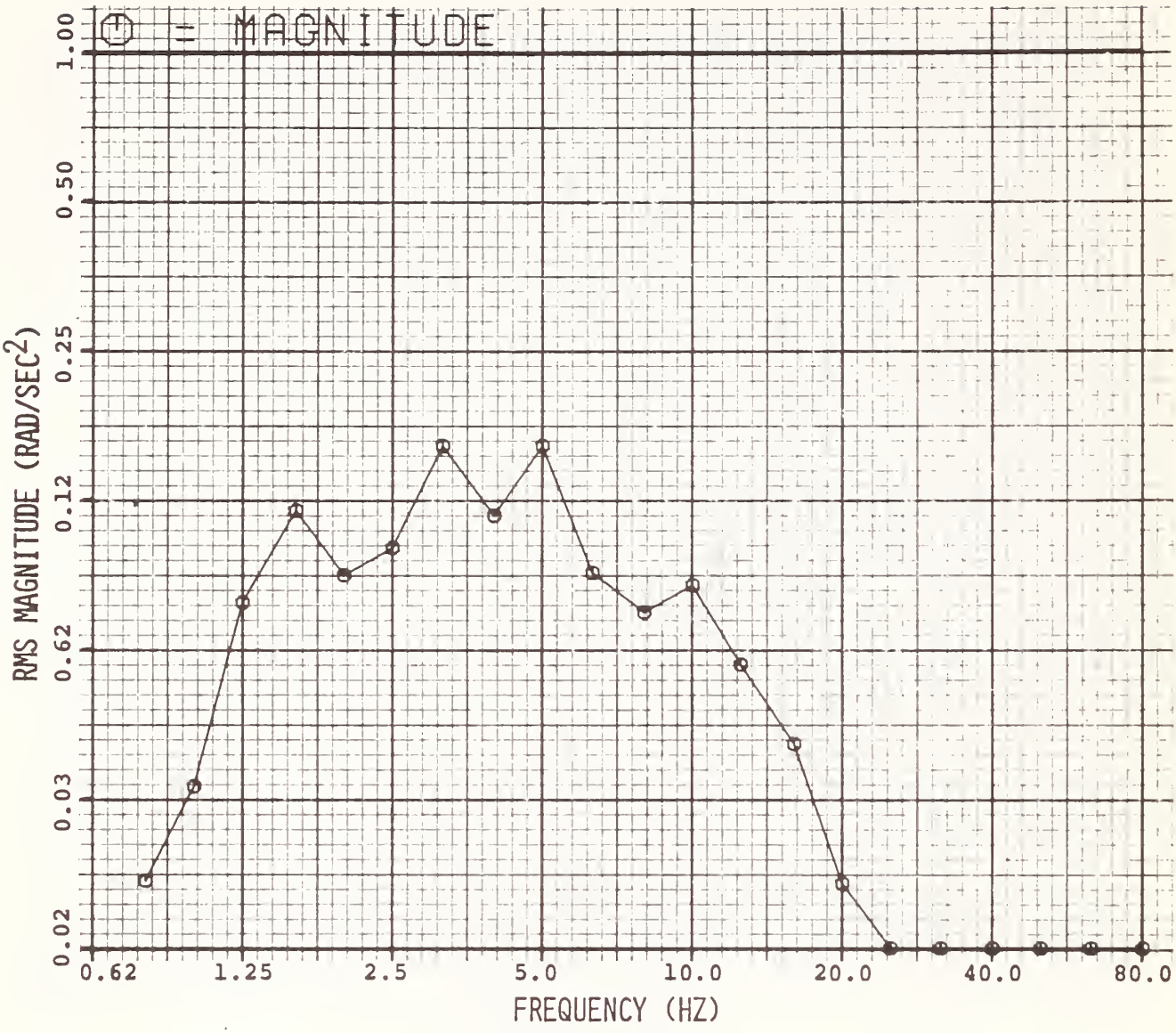


Figure E-39. Dutcher Vehicle Roll Acceleration, Heavy Load, 10 mph.

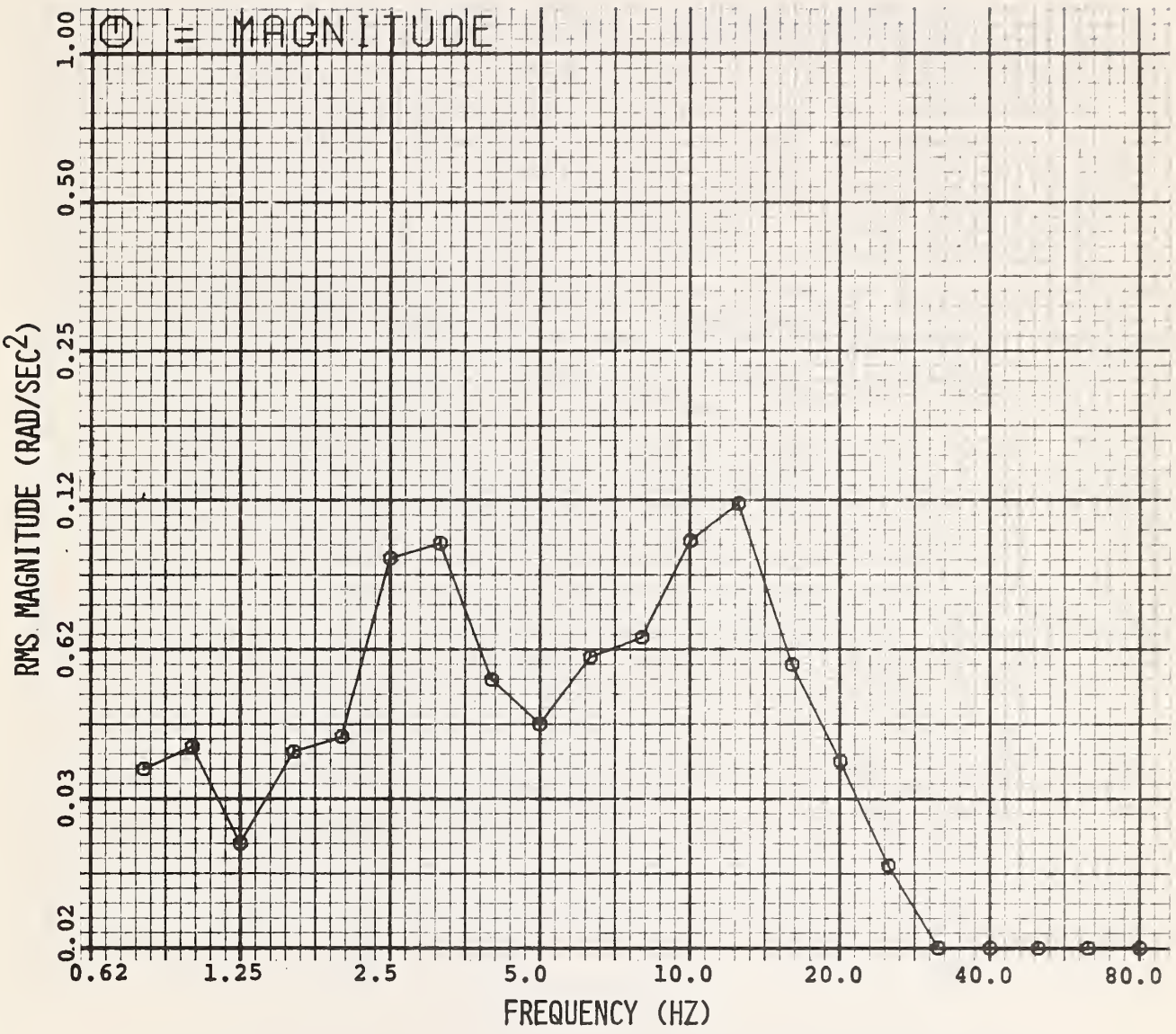


Figure E-40. Dutcher Vehicle Roll Acceleration, Heavy Load, 20 mph.

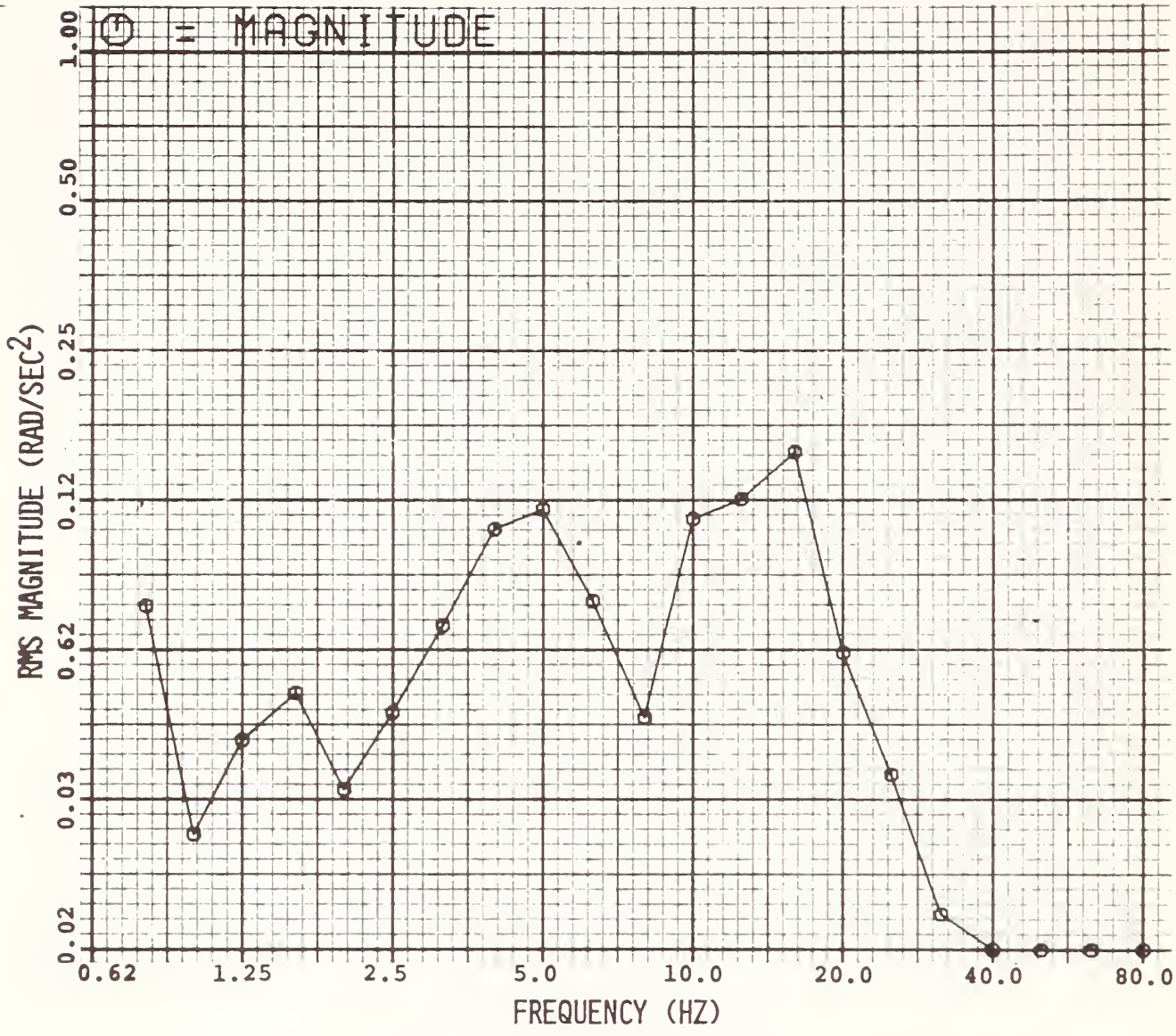


Figure E-41. Dutcher Vehicle Roll Acceleration, Heavy Load, 30 mph.

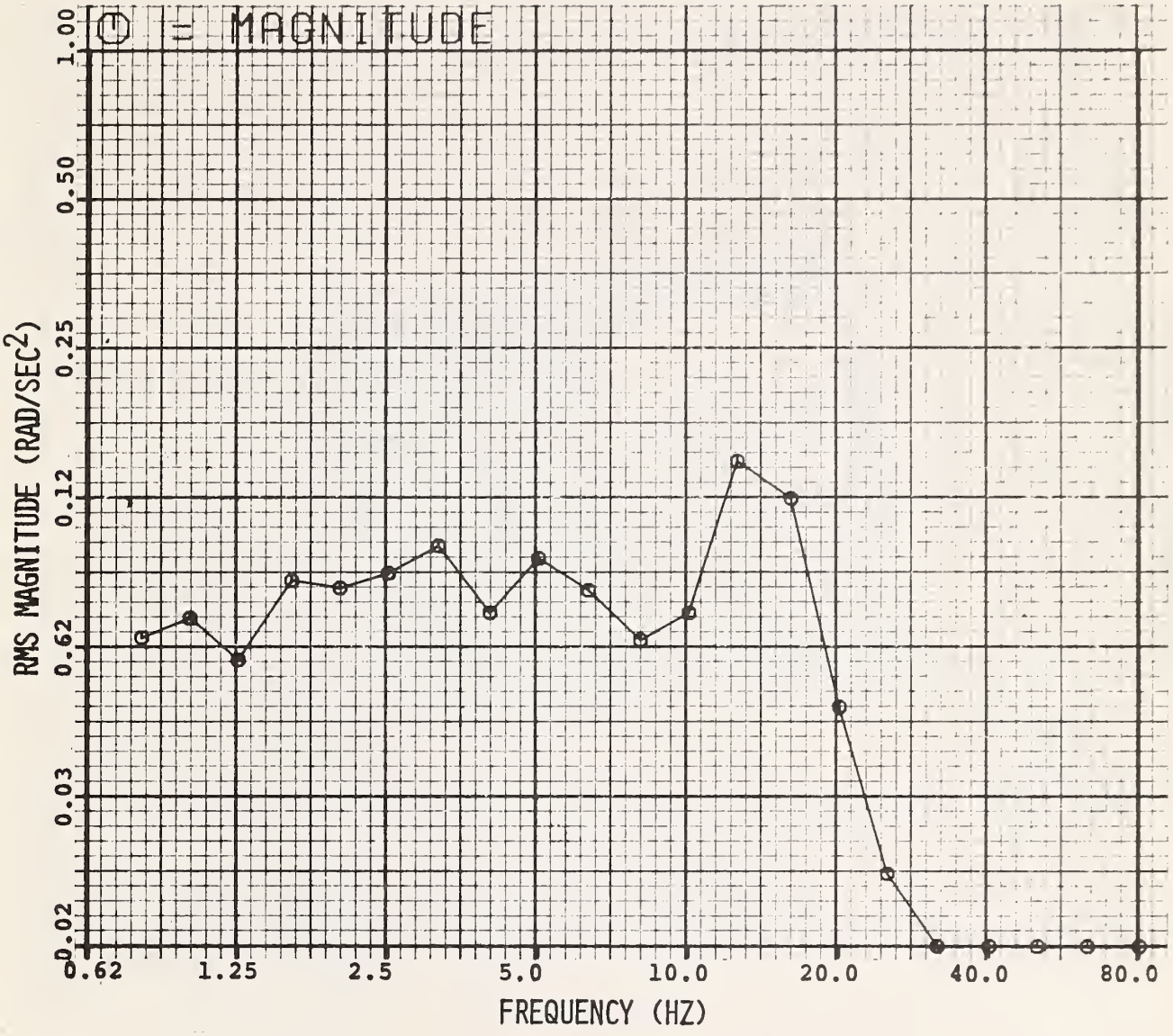


Figure E-42. Dutcher Vehicle Roll Acceleration, Heavy Load, 40 mph.

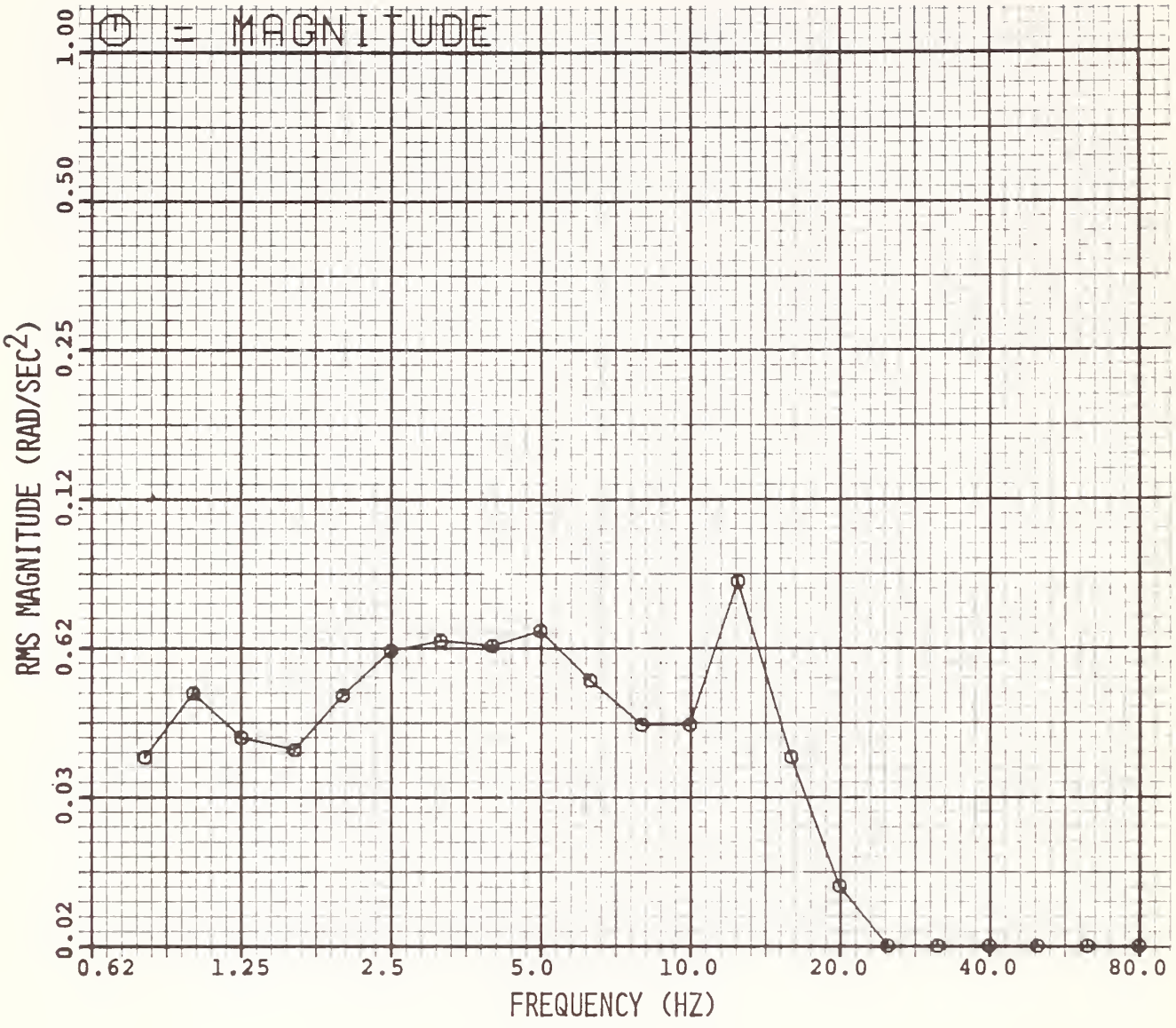


Figure E-43. Dutcher Vehicle Roll Acceleration, Urban Driving Course.

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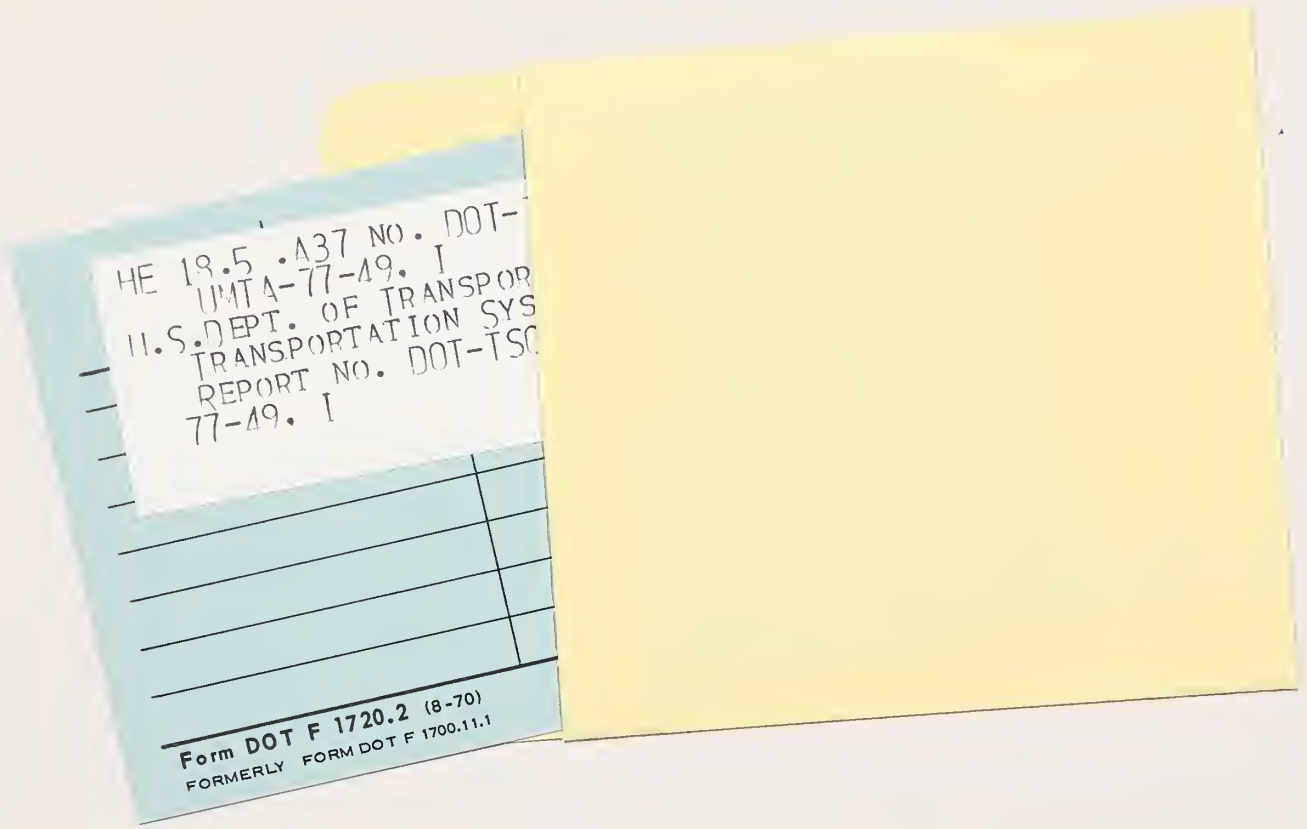

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